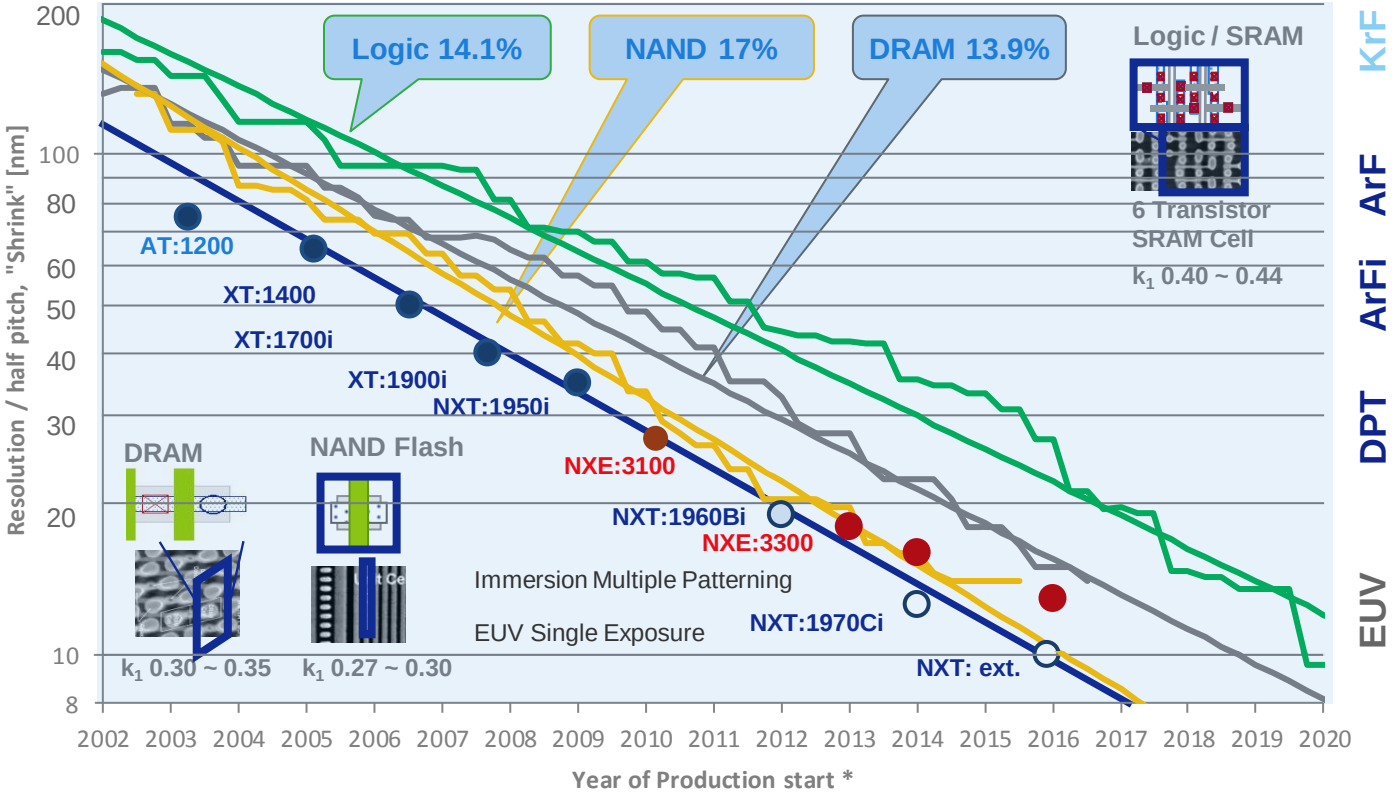
ASML's NXE platform performance and volume introduction

Rudy Peeters

2013 SPIE Advanced Lithography, San Jose CA, 8679-50

Industry roadmap towards < 10 nm resolution

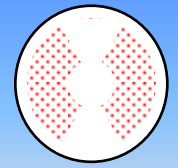
Lithography supports shrink roadmap



* Note: Process development 1.5 ~ 2 years in advance updated Dec/12

NXE technology roadmap has great extendibility

					Under study			
Resolution [nm]	**32**	**27**	**22**	**16**	**13**	**10**	**7**	**<7**
Wavelength [nm]	13.5							
Lens NA	0.25		0.33			0.33NA DPT		0.45-0.60 DPT
Lens NA						0.45	0.60	
Lens flare	8%		6%	4%				
Illumination coherence	σ=0.5	σ=0.8	σ=0.2-0.9	Flex-OAI	Extended Flex-OAI			
Illumination					reduced pupil fill ratio			
Overlay DCO [nm]	7	4.0	3.0	1.5	1.2	1.0		
Overlay MMO [nm]	-	7.0	5.0	2.5	2.0	1.7		
TPT (300mm) Dose [mJ/cm²]	5	10	15	15	20	20		
TPT (300mm) Power [W]	3	10 - 105	80 - 250	250	250	500		
TPT (300mm) Throughphut [w/hr]	-	6 - 60	50 - 125	125	125	165		



pupil fill ratio defined as the bright fraction of the pupil

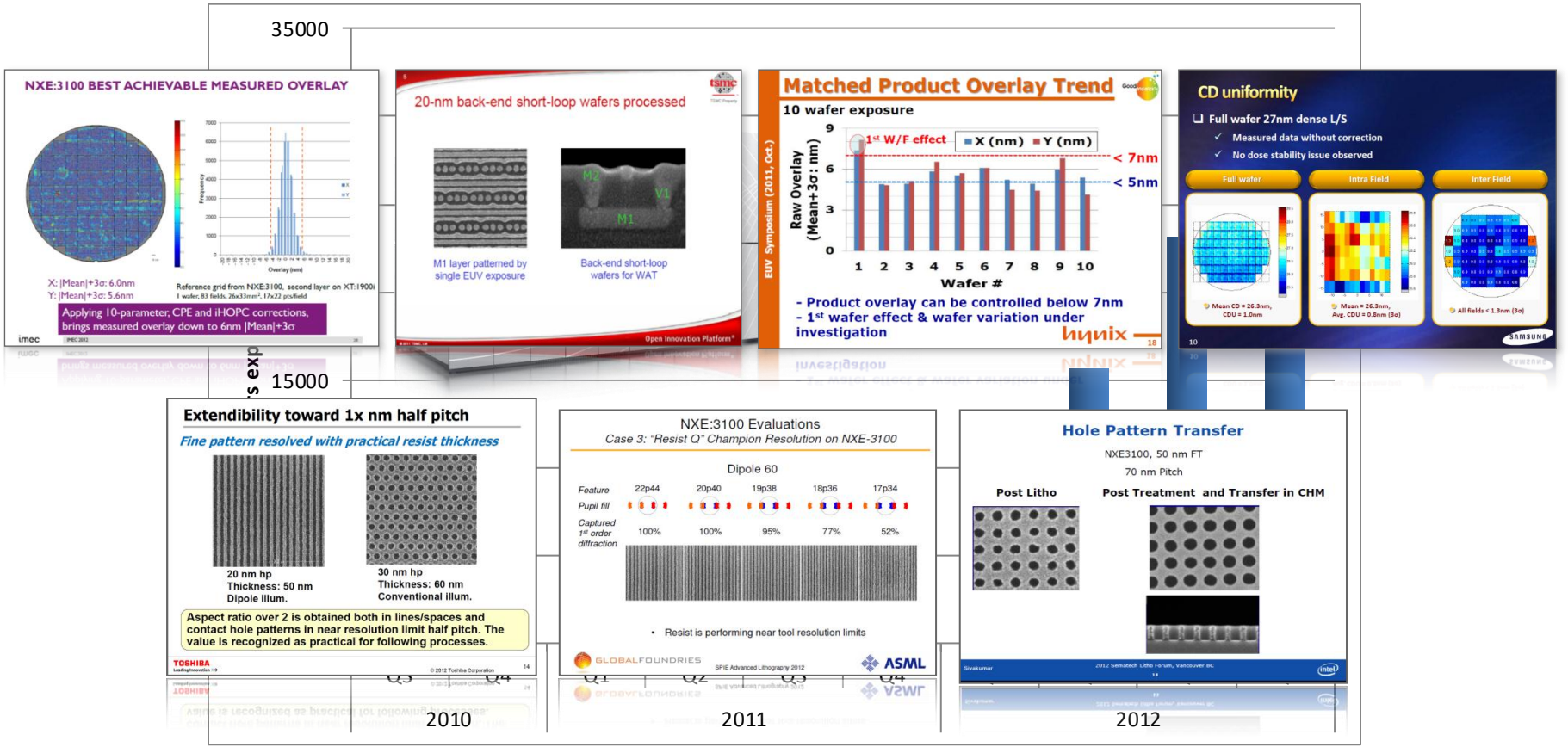
ASML's NXE:3100 and NXE:3300B

	NXE:3100	NXE:3300B
NA	0.25	0.33
Illumination	Conventional 0.8 σ	Conventional 0.9 σ Off-axis illumination
Resolution	27 nm	22 nm
Dedicated Chuck Overlay / Matched Maching Overlay	4.0 nm / 7.0 nm	3.0 nm / 5.0 nm
Productivity	6 - 60 Wafers / hour	50 - 125 Wafers / hour
Resist Dose	10 mJ / cm2	15 mJ / cm2

Contents

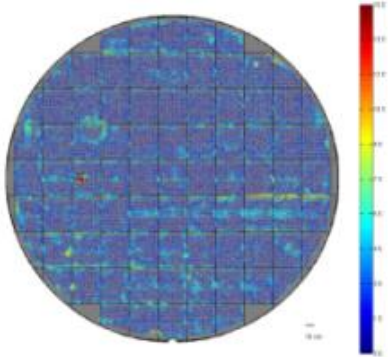
The NXE:3100 has exposed >30,000 wafers

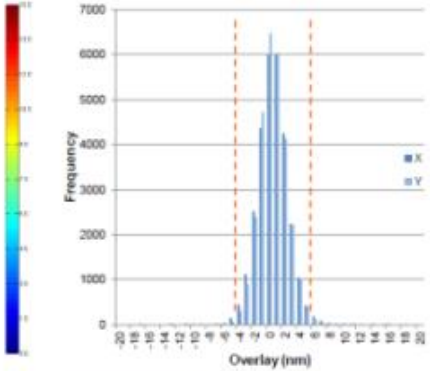
Enabling customers to go through cycles of learning



Good overlay on NXE:3100 at customers

NXE:3100 BEST ACHIEVABLE MEASURED OVERLAY





X: |Mean|+3σ: 6.0nm
Y: |Mean|+3σ: 5.6nm

Reference grid from NXE:3100, second layer on XT:1900i
1 wafer, 83 fields, 26x33mm², 17x22 pts/field

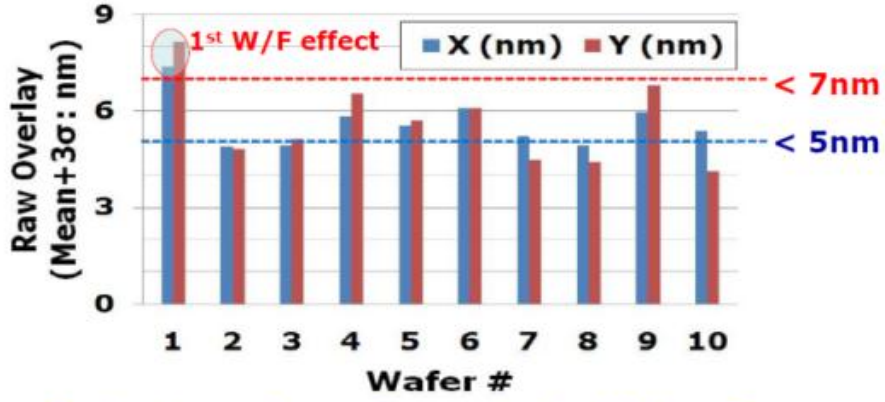
Applying 10-parameter, CPE and iHOPC corrections, brings measured overlay down to 6nm |Mean|+3σ

imec

Matched Product Overlay Trend

EUV Symposium (2011, Oct.)

10 wafer exposure



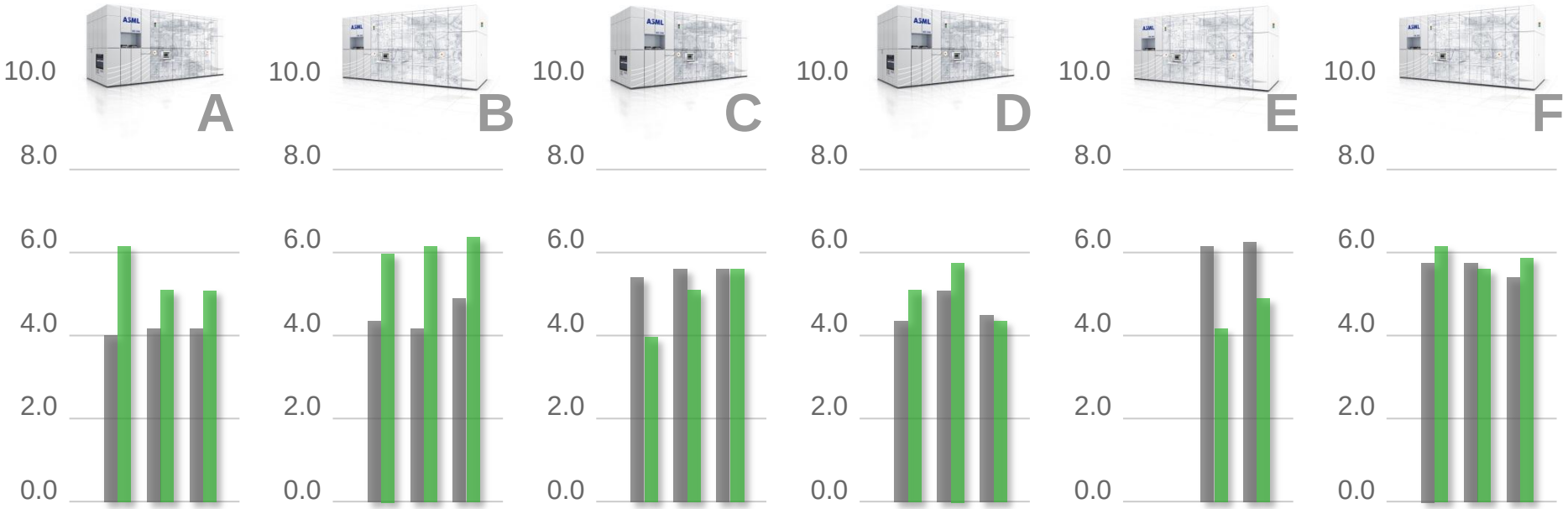
- Product overlay can be controlled below 7nm
- 1st wafer effect & wafer variation under investigation

hynix

18

And consistent good overlay for all NXE:3100 tools

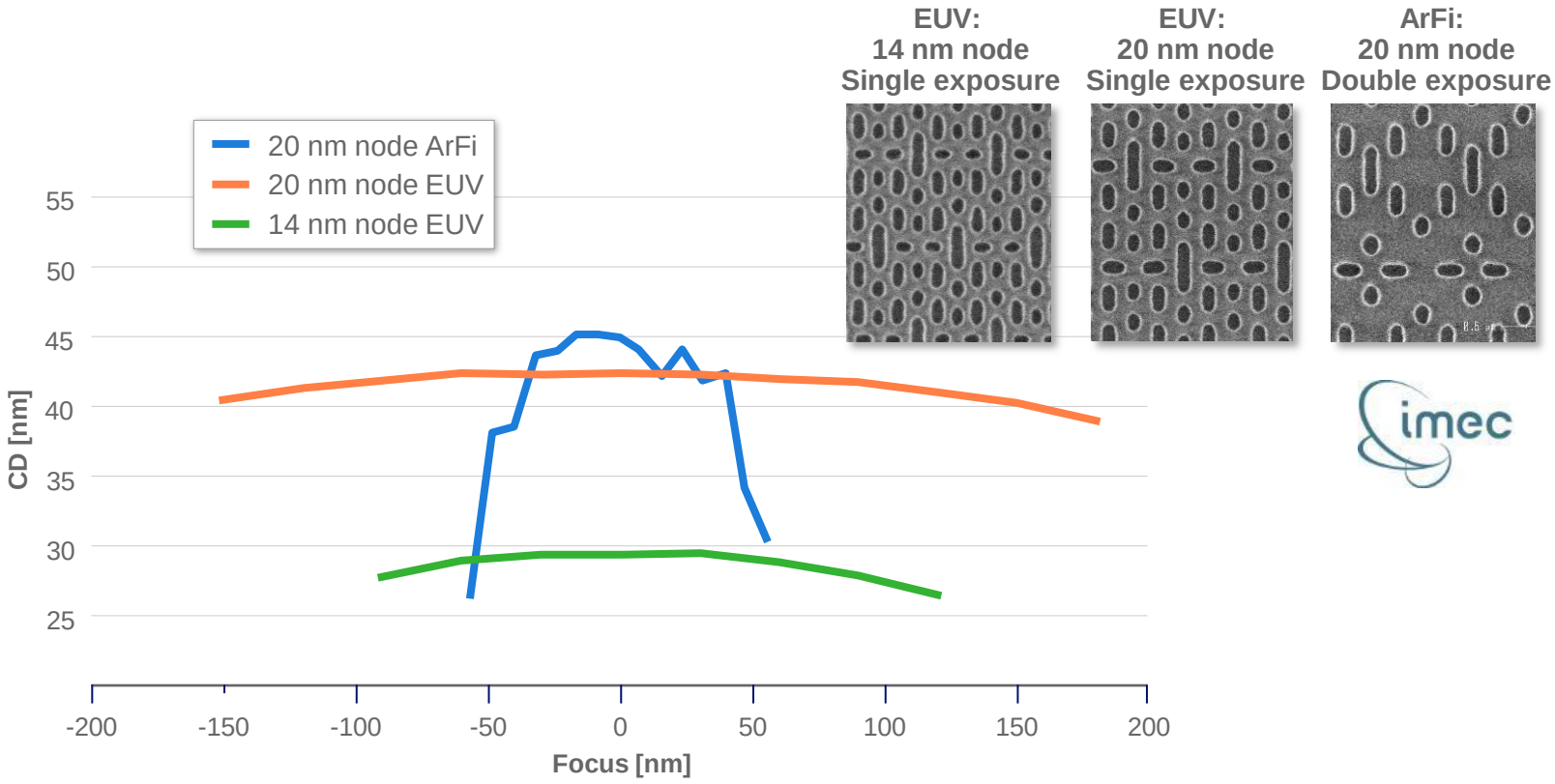
Matched Machine Overlay ~6 nm



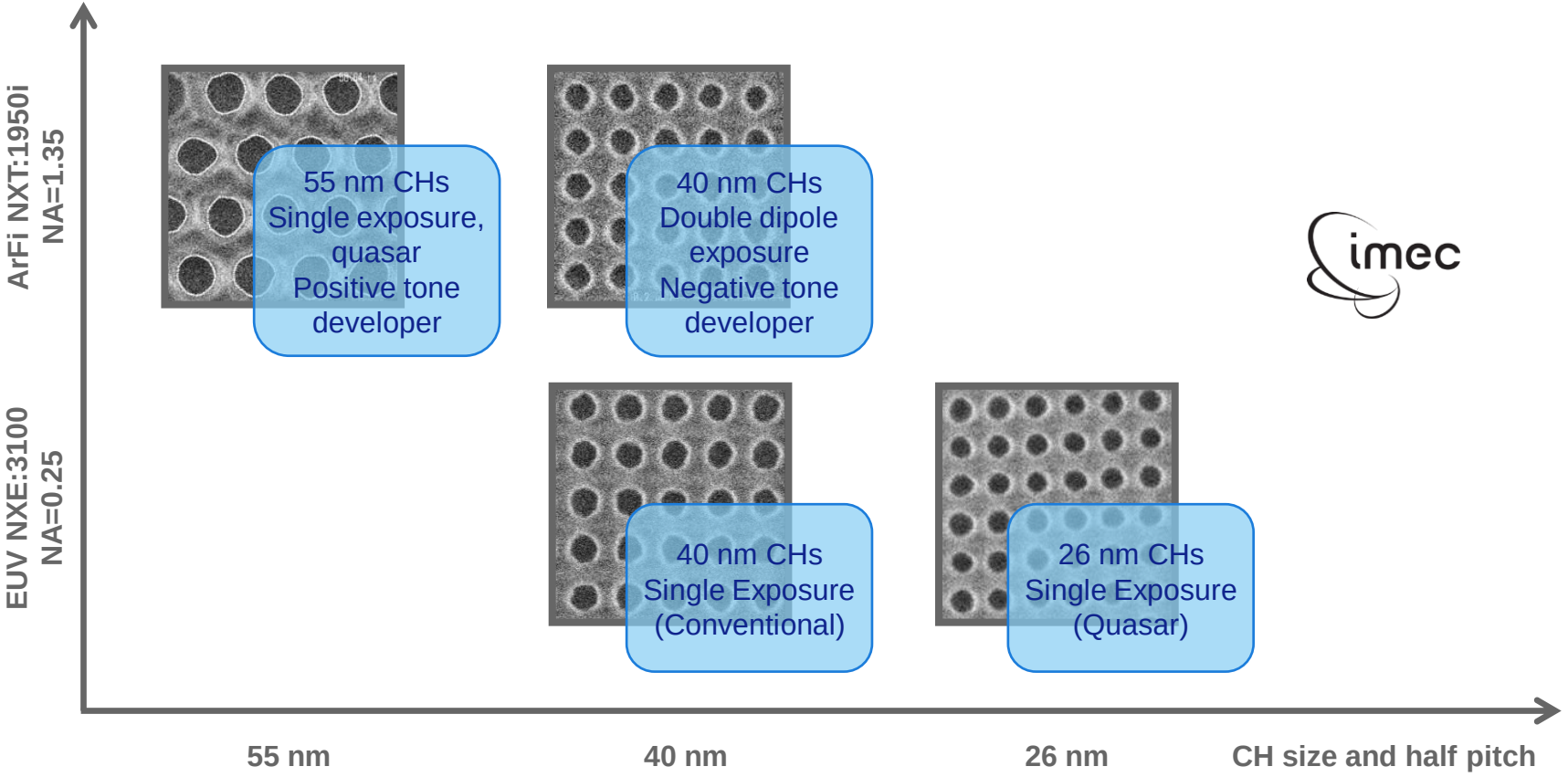
All numbers are (X,Y) matched machine overlay results to an ArF reference wafer using ASML standard test method

Large process windows measured on the NXE:3100

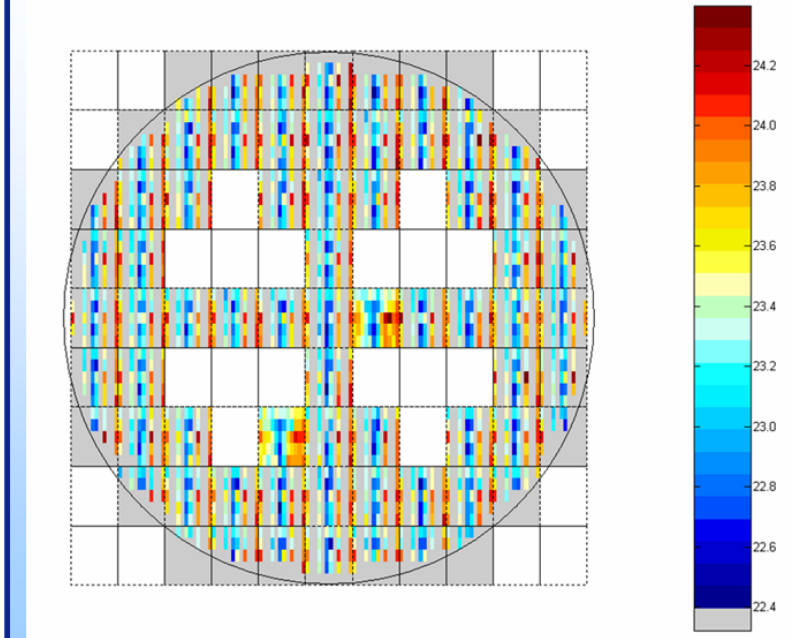
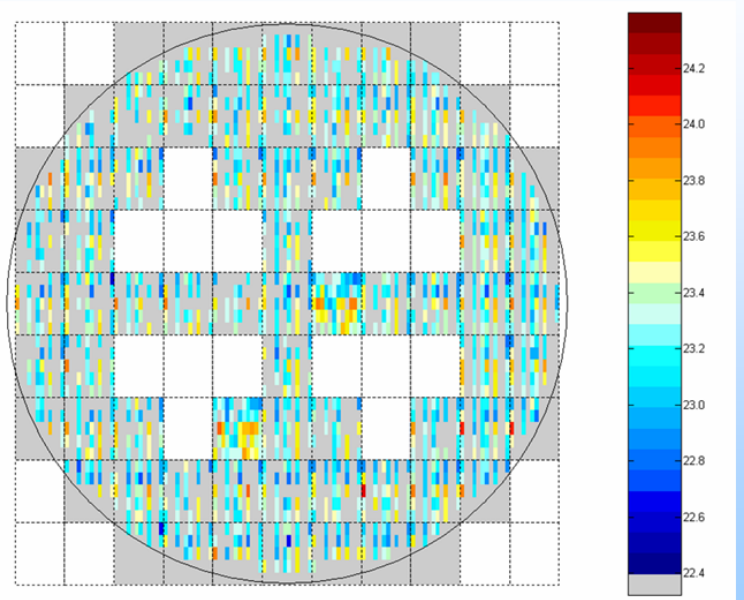
Down to 14 nm node SRAM M1 layer



Dense CH imaging down to 26 nm on NXE:3100



Customer NXE:3100 CDU result

FWCDU DIPY75; Horizontal	FWCDU DIPX75; Vertical
	
Mean H CD = 23.4nm, H CDU = 1.3nm	Mean V CD = 23.3nm, V CDU = 0.7nm

Contents

Eleven NXE:3300B systems in various states of integration new clean room completely finalized in July ‘12

System 1

Development tool

System 2

System 9

System 6

New cleanroom

System 3

System 7

System 4

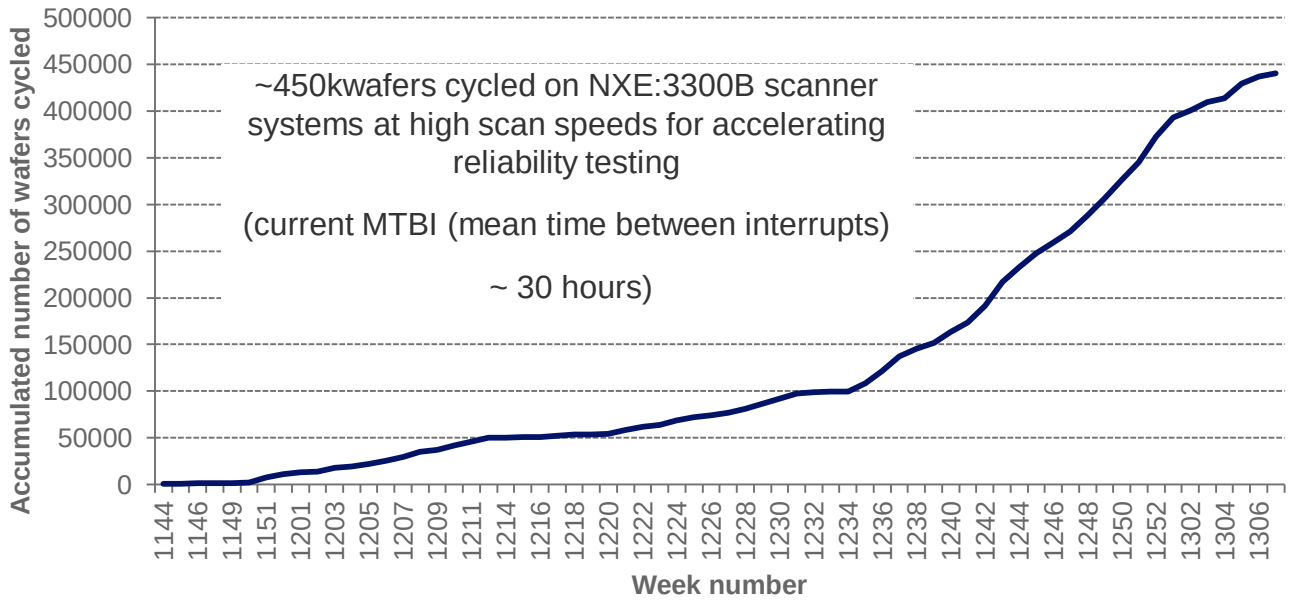
System 5

System 8

System 10
Training

Contents

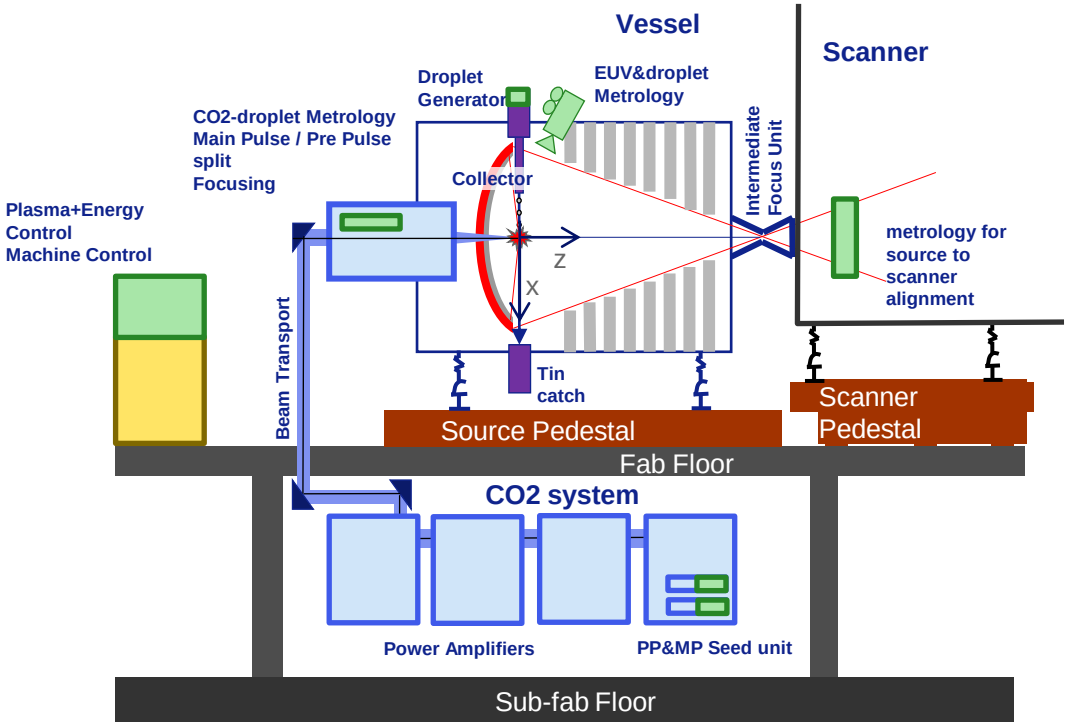
~450,000 wafer cycled on NXE:3300B for integration and reliability testing



Stages dynamics performance demonstrated up to 100 wafers per hour

		100 wafers per Hour	
	unit	Required	NXE 3300B results
Move parameters			
Step velocity	**[m/s]**	**1**	**1**
Scan velocity expose	**[m/s]**	**0.25**	**0.25**
Scan acceleration expose x/y	**[m/s^2]**	**35/25**	**35/25**
Scan velocity measure	**[m/s]**	**1**	**1**
Jerk x/y	**[m/s^3]**	**3500/2500**	**3500/2500**
WS accuracy at expose			
MA-xy	**[nm]**	**1**	**1**
MA-z	**[nm]**	**6**	**4.2**
MSD-xy	**[nm]**	**2.2**	**2.1**
MSD-z	**[nm]**	**21**	**9.1**
Total (WS-RS/4) accuracy at expose			
MA-xy	**[nm]**	**0.6**	**0.4**
MA-z	**[nm]**	**6**	**4.2**
MSD-xy	**[nm]**	**2.5**	**1.9**
MSD-z	**[nm]**	**21**	**9.1**

EUV source system cross-section



x=droplet stream direction, z=CO2 light direction, y=orthogonal

Key components:

- Drive Laser
- Droplet generator
- Vessel

Power

- Final Focus Assembly
- Collector

Availability

- Controls (E,x,y,z,t)

Dose control

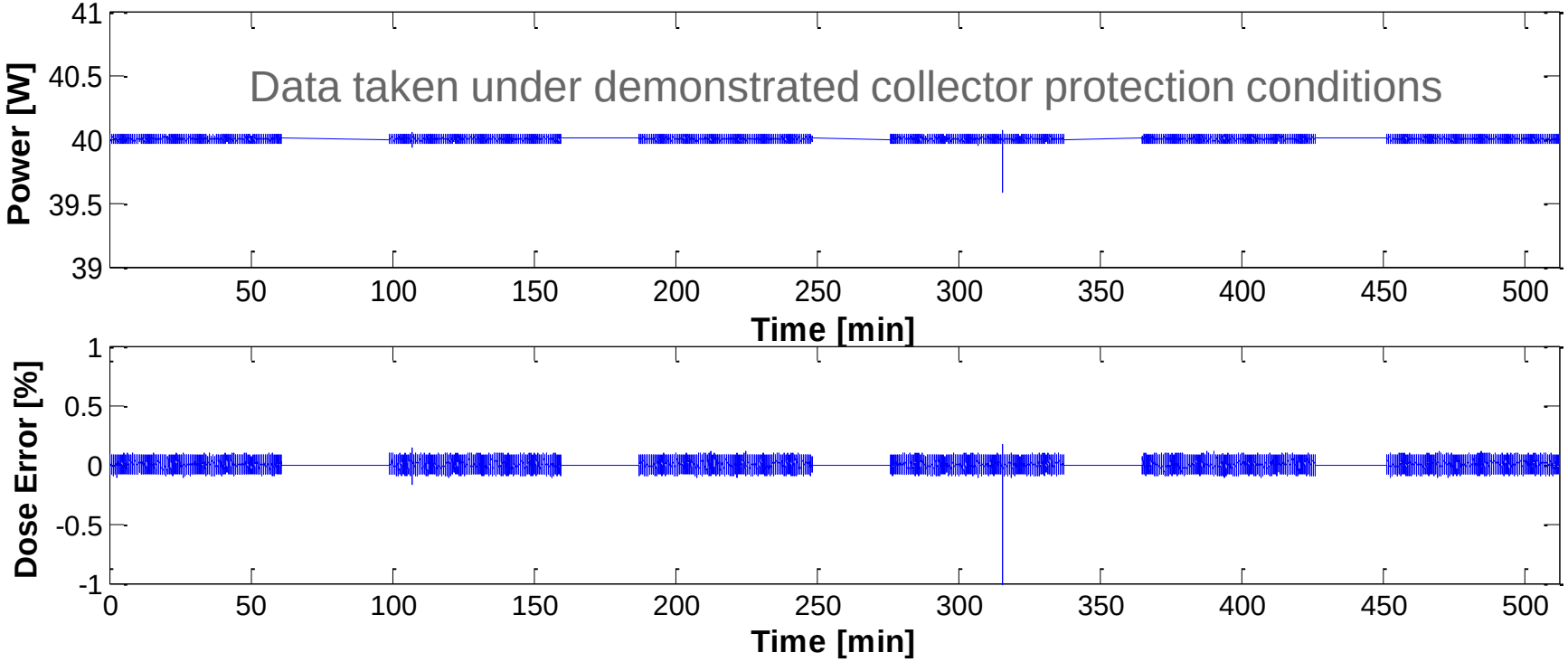
Presentation: David Brandt (Cymer)

MOPA PrePulse Technology Validated with Power, Dose Stability and Collector Protection

Power	Dose Control	Availability	Comment
40W	99.99% of dies <0.2% dose repro, 100% duty cycle within die exposure and at full closed loop control	Proven Collector Protection settings	six 1-hour runs during 8.5 hours of operation
55W	97.5% of dies <0.5% dose repro, 100% duty cycle within die exposure and at full closed loop control	Proven Collector Protection settings	1 hour of operation
up to 60W	Open Loop	Proven Collector Protection Over 4Bpls, 40hours continuous exposures	Dedicated test to demonstrate collector protection

Presentation: David Brandt (Cymer)

40W stable dose control performance for six 1-hours for MOPA-PrePulse

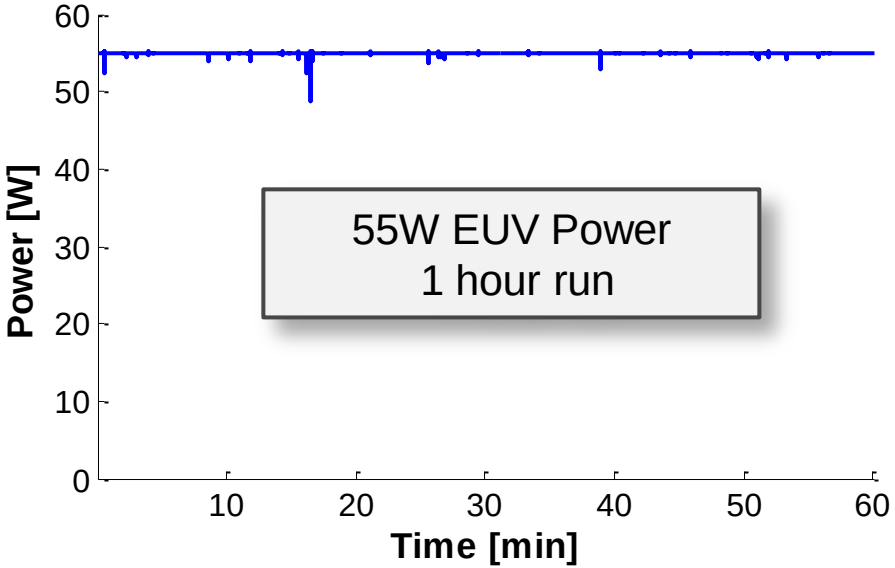


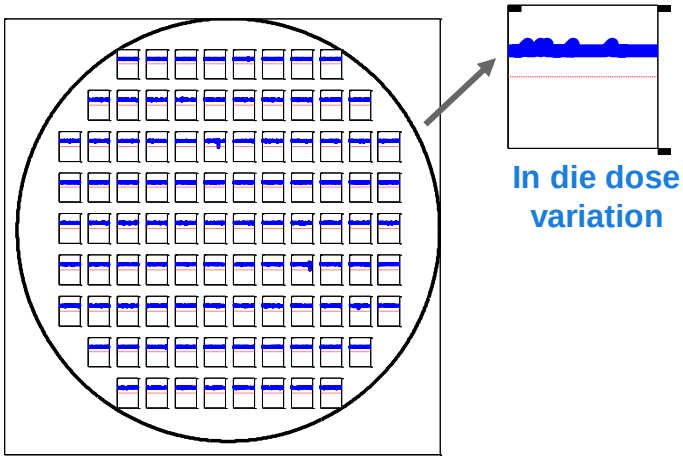
- 196 equivalent wafer exposures with 99.99% die yield

Presentation: David Brandt (Cymer)

55W EUV Power Demonstrated using MOPA Prepulse

Good dose control and under collector protection conditions



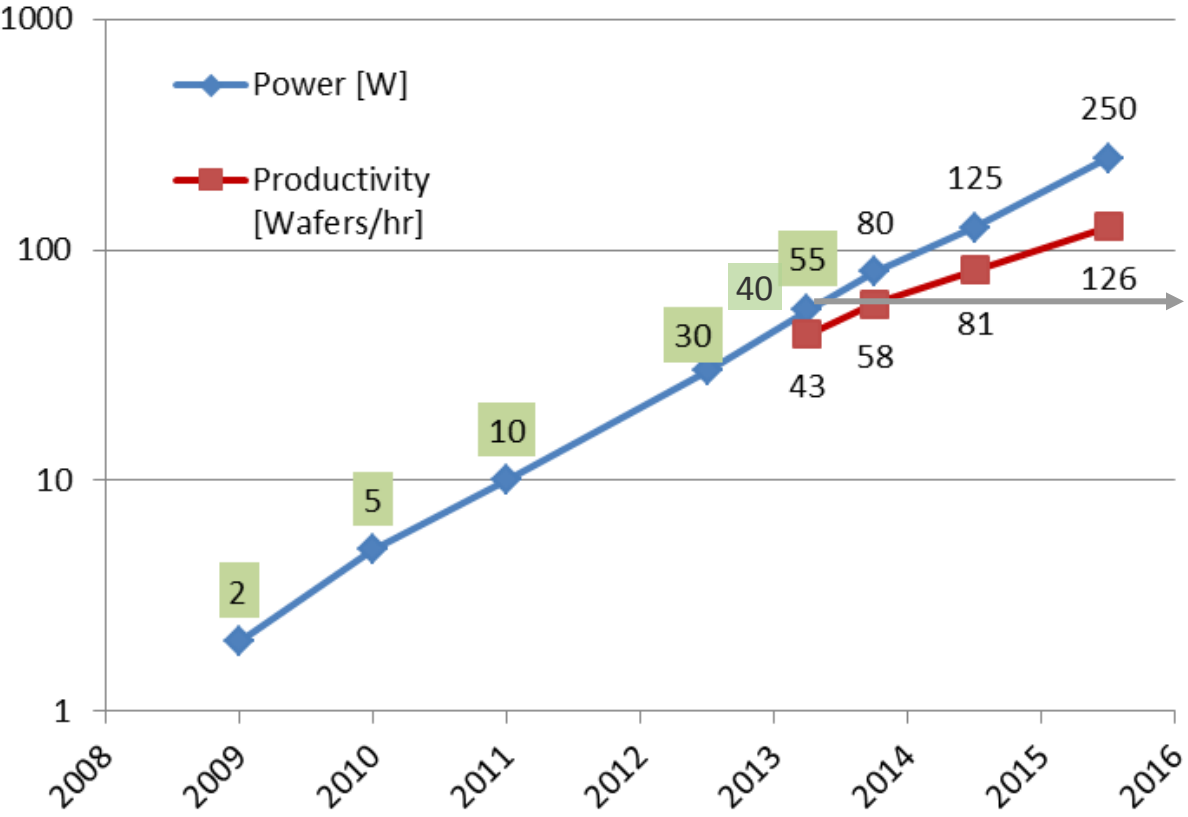


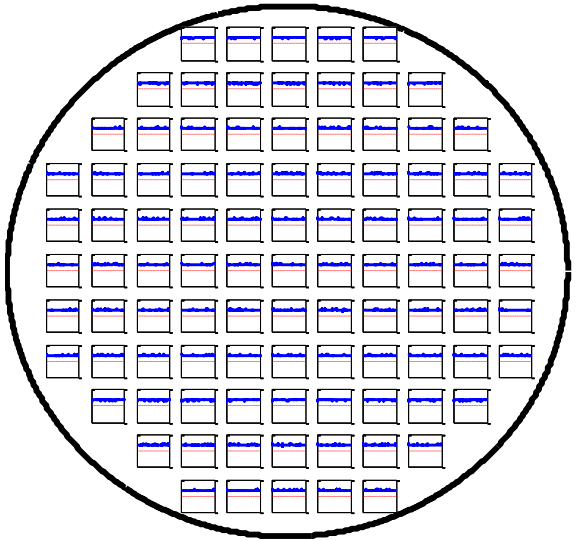
55W EUV Power with
97.5% die yield

Presentation: David Brandt (Cymer)

EUV Source Power Progress reaching 55 W

Supporting 43 Wafers/hr, 250 W target to be reached in 2015





At 55 W, 1 run:
97.5% of the dies < 0.5% dose

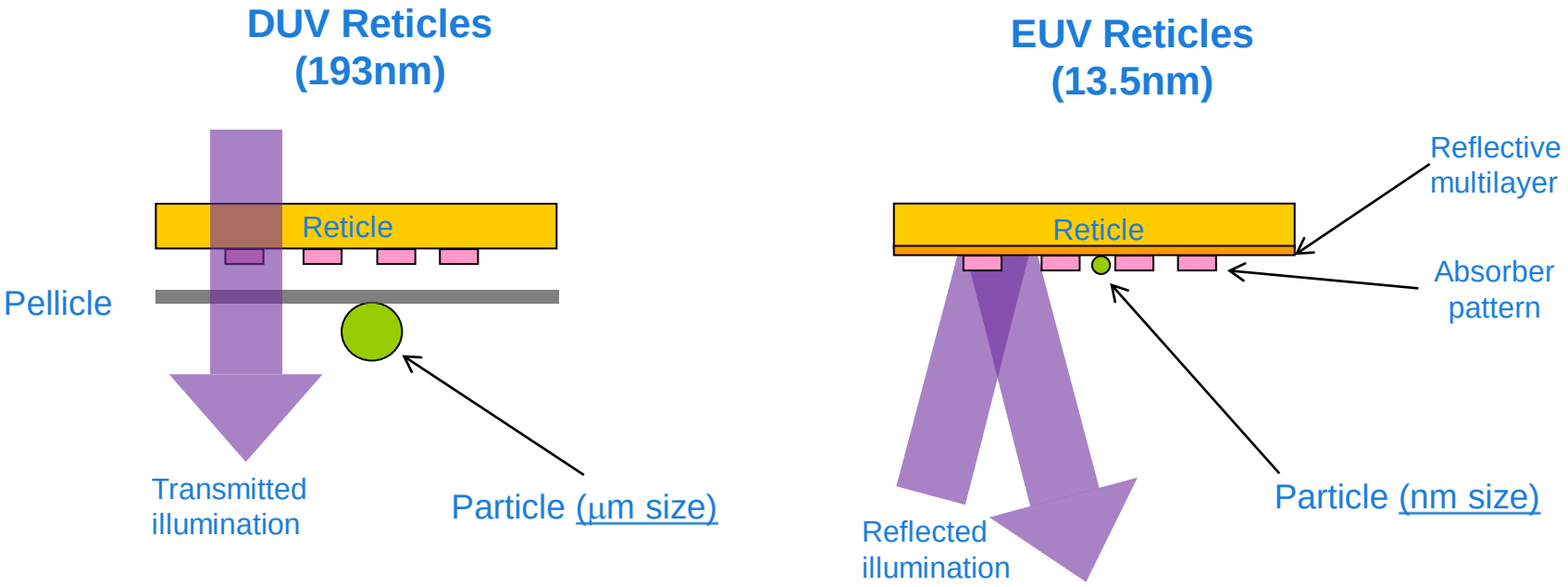
At 40 W, 6 runs:
99.99 of the dies < 0.2% dose,

7 one hour runs total representing
~ 250 exposed wafers @ 15 mJ/cm²

Contents

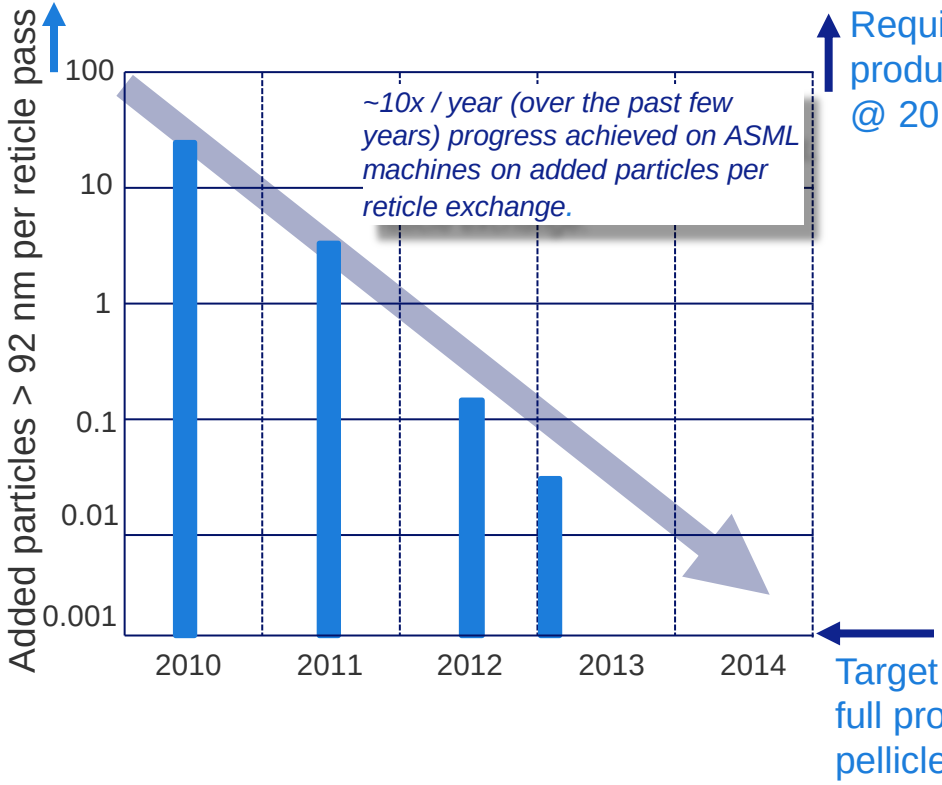
The mask defect challenge

Challenging defect requirements on reflective pellicle less EUV mask

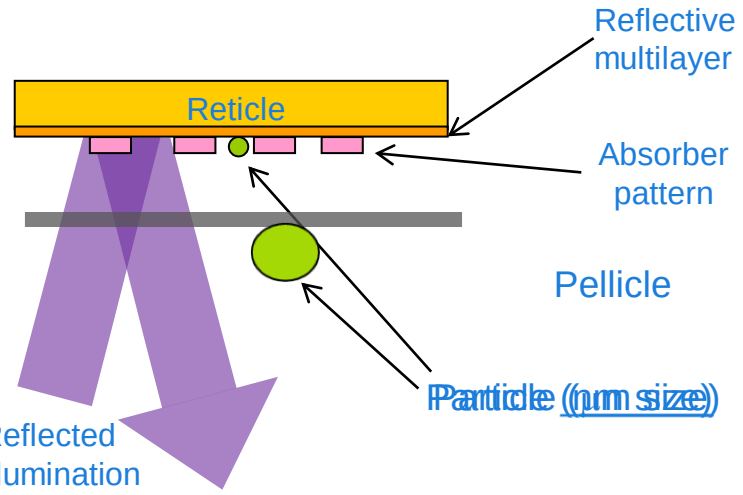


Substantial progress defect-free mask handling

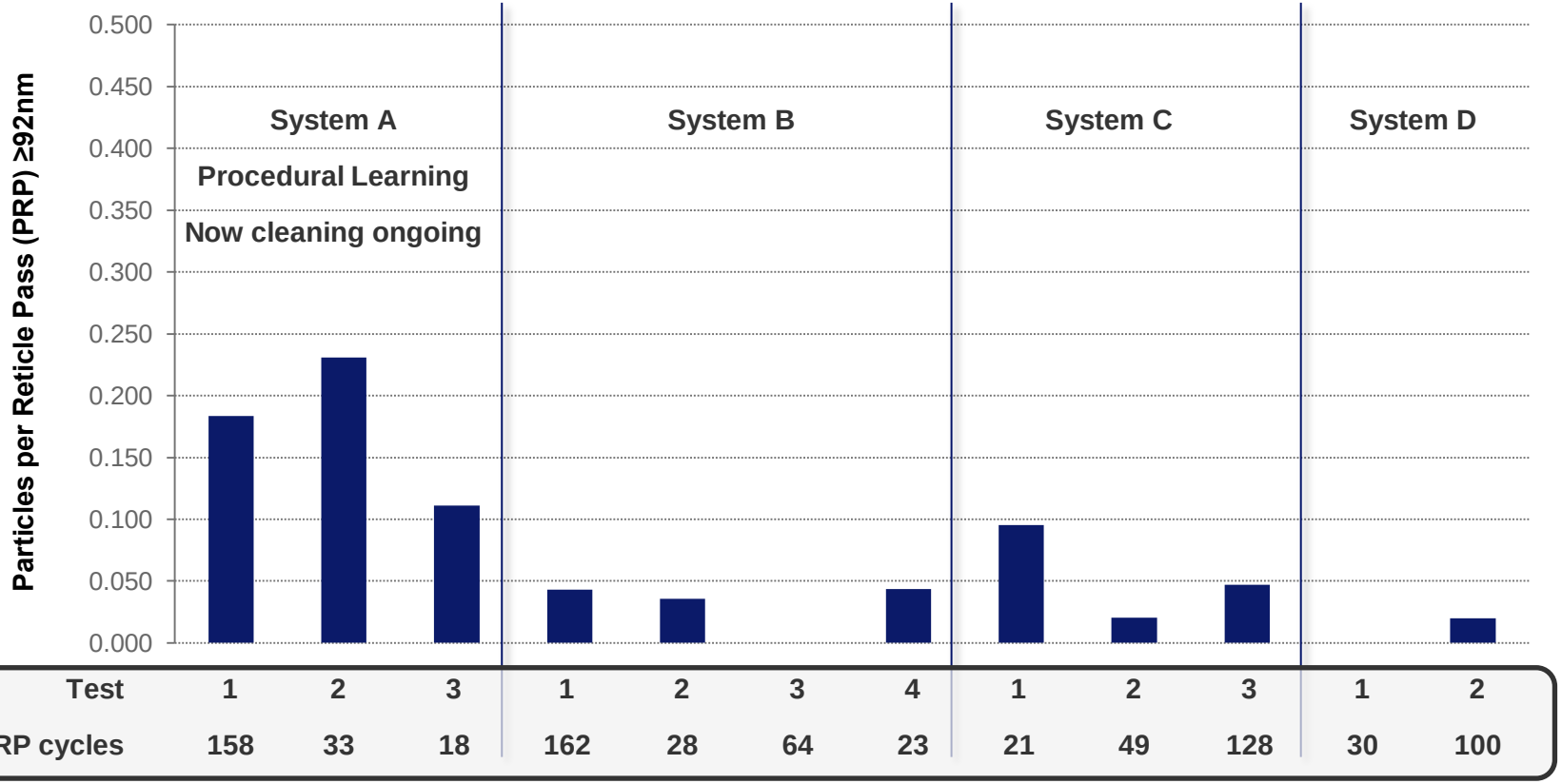
pellicle would reduce defect requirements orders of magnitude



EUV Reticles (13.5nm)

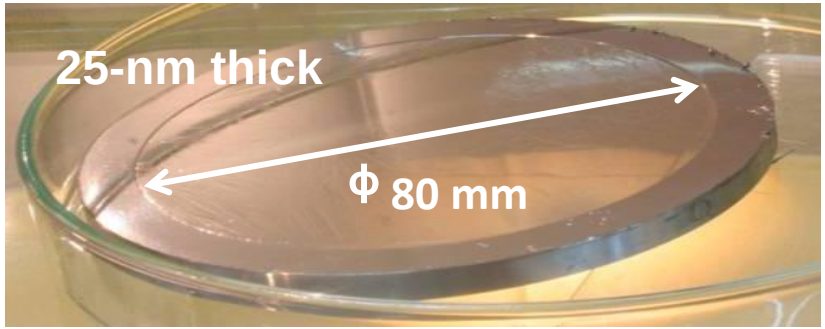


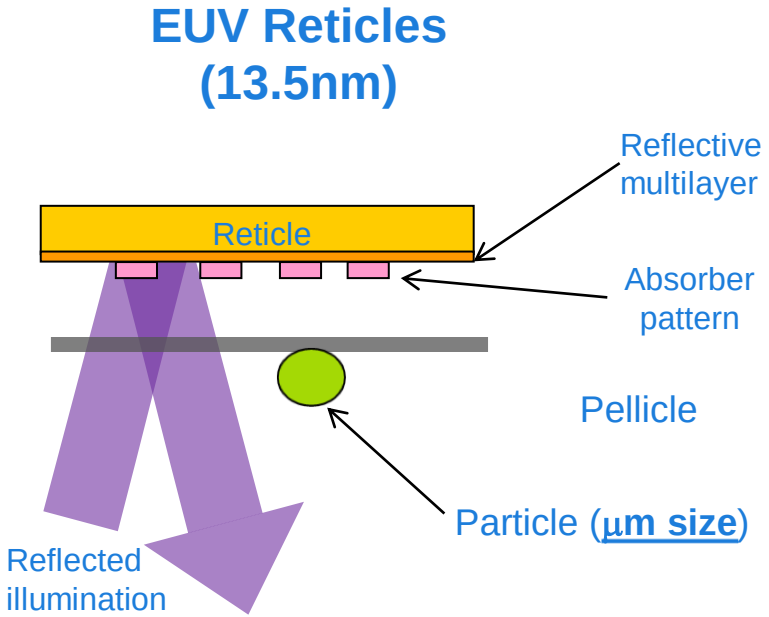
NXE:3300B particles per reticle pass performance <0.02 on multiple systems *Per PRP test 15 wafers cycled*



Test	1	2	3	1	2	3	4	1	2	3	1	2
# of PRP cycles	158	33	18	162	28	64	23	21	49	128	30	100

EUV pellicle considered as backup with minimum transmission and imaging loss



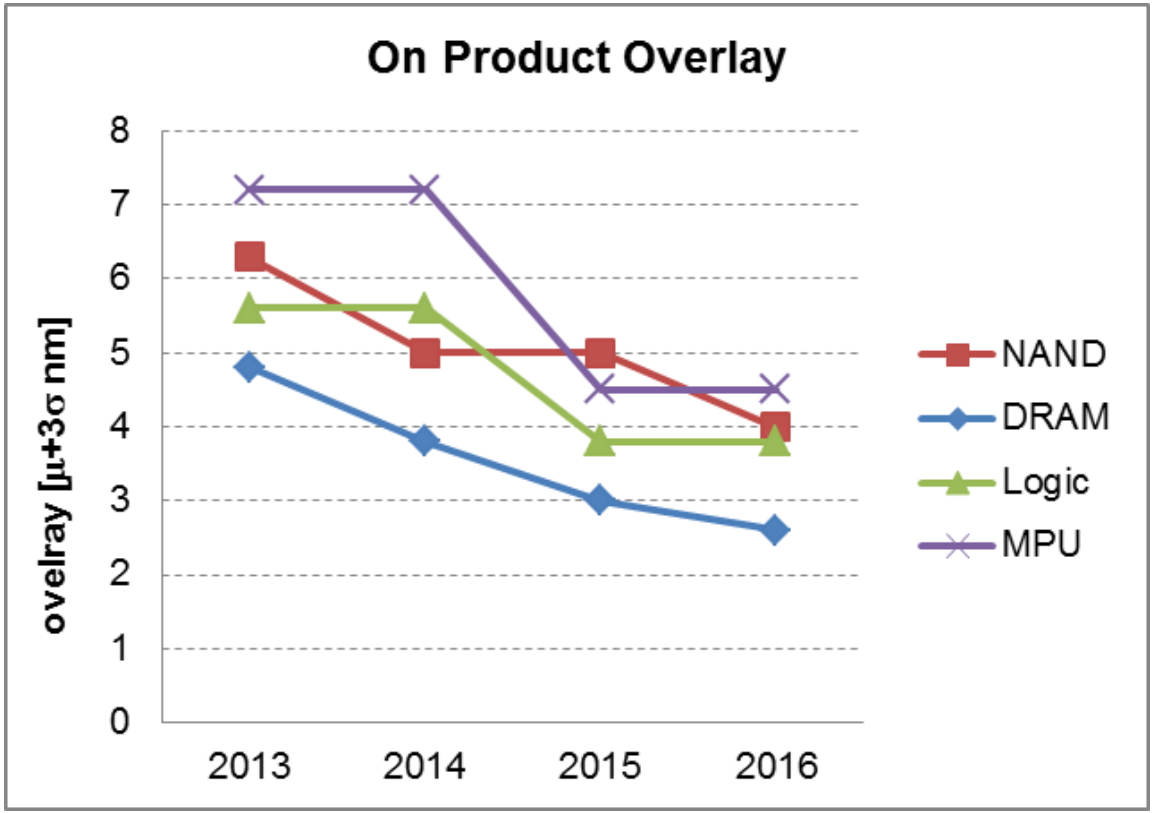


- Requirement: 90% transmission, 114x142 mm²
- Status: 87% transmission, ϕ 80 mm

Presentation: Luigi Scaccabarozzi (ASML)

Contents

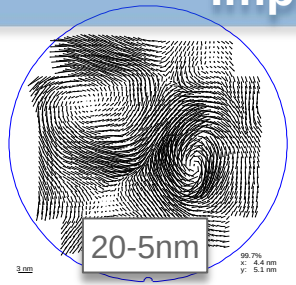
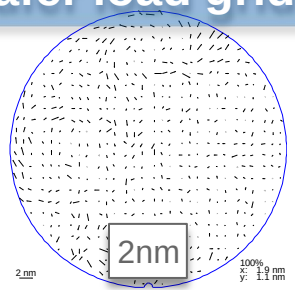
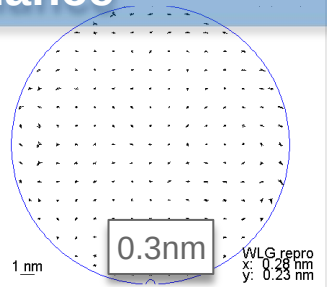
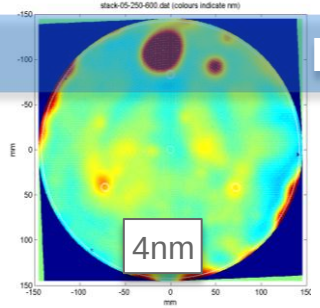
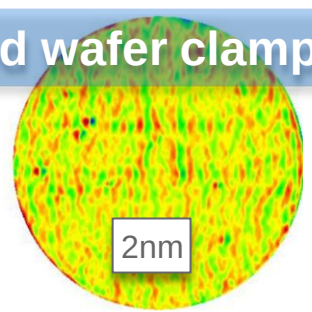
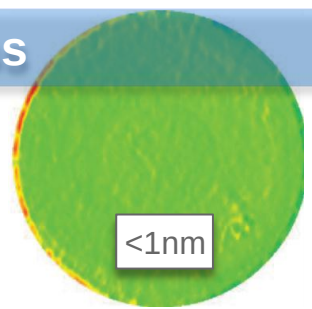
Customer On-Product-Overlay roadmap



ASML assessment based on customer inputs

NXE:3300B overlay improvements

Better wafer load grid performance and improved wafer clamp flatness

ADT	NXE:3100	NXE:3300B
Improved wafer load grid performance		
		
Improved wafer clamp flatness		
		

Measured by repeatedly clamping a wafer

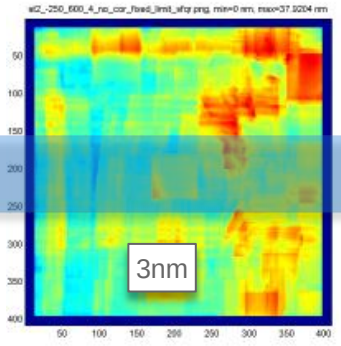
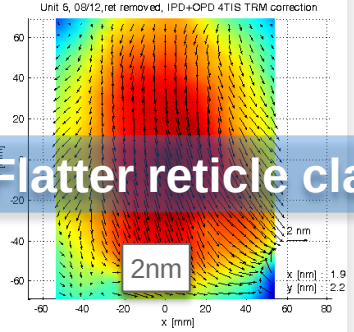
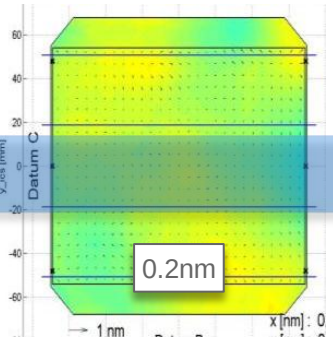
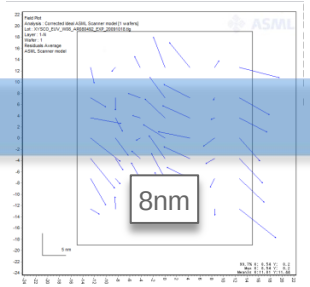
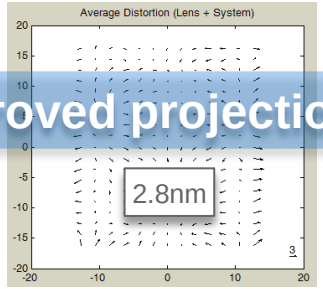
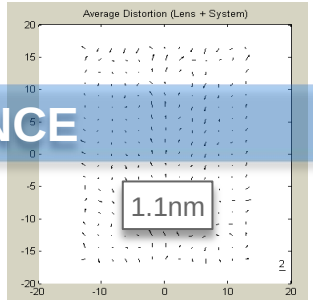
Measured heightmap with interferometer

Translated into overlay via model

Numbers show the contribution to overlay, budget is RSS of multiple components

NXE:3300B overlay improvements

Better lens performance and improved reticle clamp flatness

ADT	NXE:3100	NXE:3300B
 3nm	 2nm	 0.2nm
 8nm	 2.8nm	 1.1nm

Measured heightmap with interferometer

Translated into overlay via model

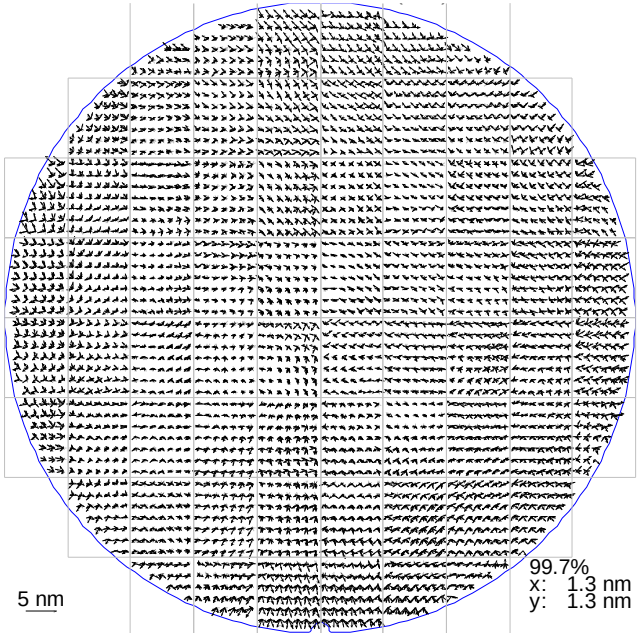
Flatter reticle clamps

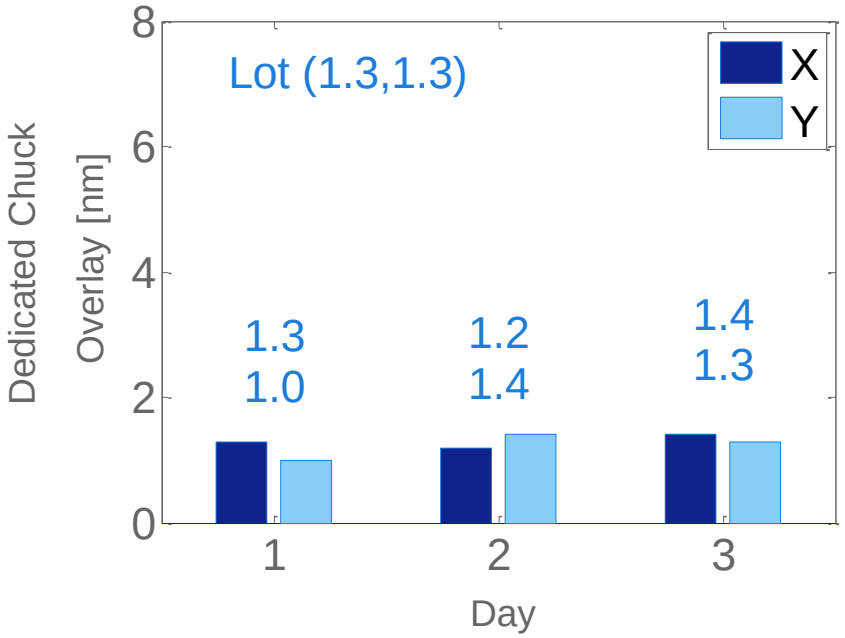
Improved projection lens NCE

Measured lens performance

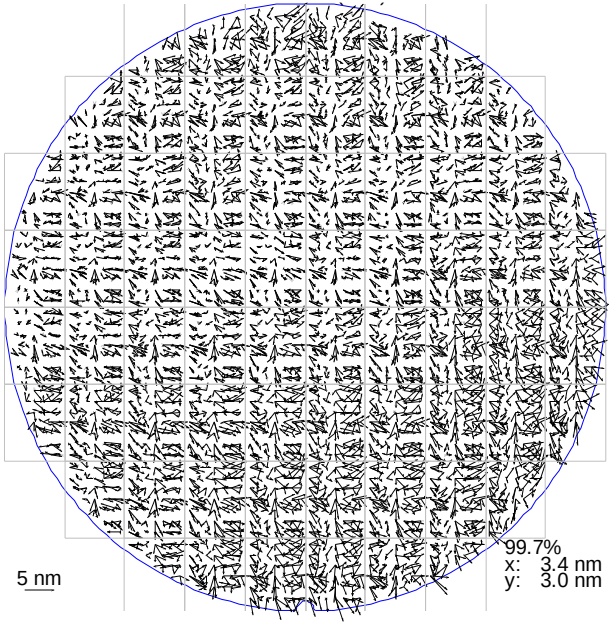
Numbers show the contribution to overlay, budget is RSS of multiple components

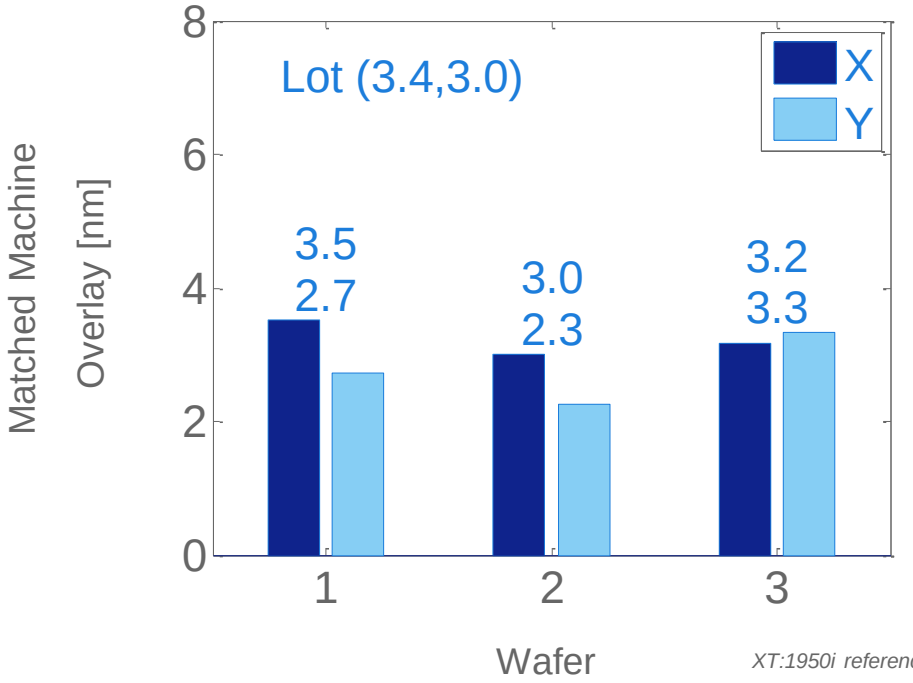
Full wafer dedicated chuck overlay of <1.4nm





NXE-Immersion Matched Machine Overlay of <3.5nm





XT:1950i reference wafers
EEXY subrecipes
18par (avg field) +
CPE (6 par per field)

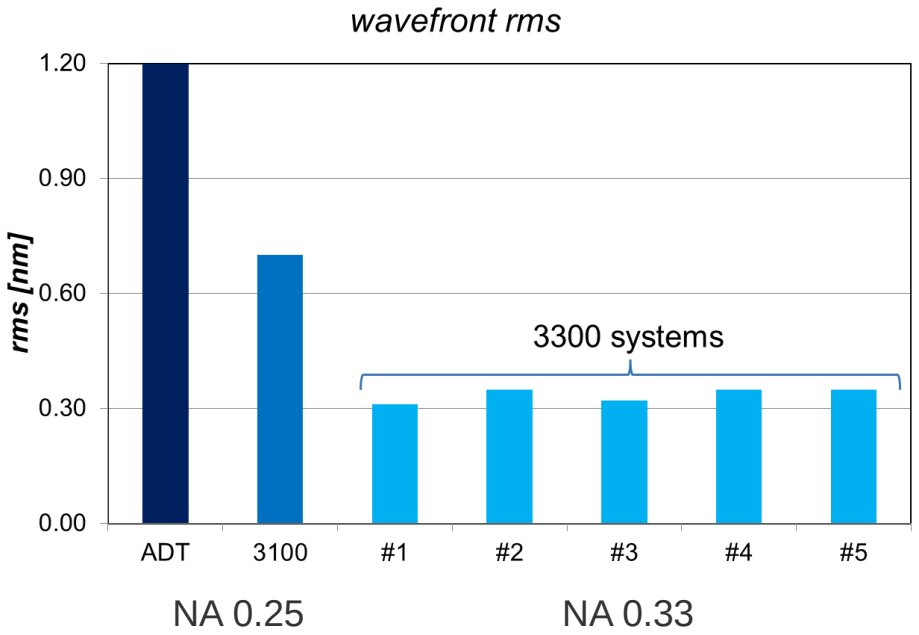
Contents

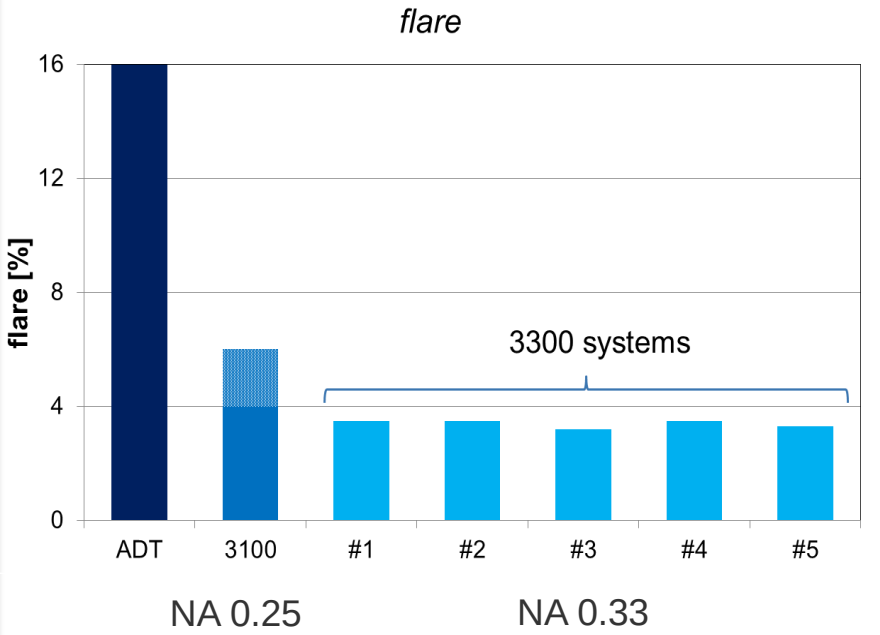
NXE:3300B imaging overview

- Optics
  - 0.33NA lens performance improvement and new off-axis illuminator
- 1D
  - 22nm dense and isolated line-space, process window and dose reduction
  - 16nm line-space and process window
- 2D
  - 24nm Contact Holes for 1x DRAM node
  - Logic 23nm half-pitch Metal 1
  - SRAM 10nm tip-to-tip and line-ends
- Resolution
  - Line-space and Contact Holes

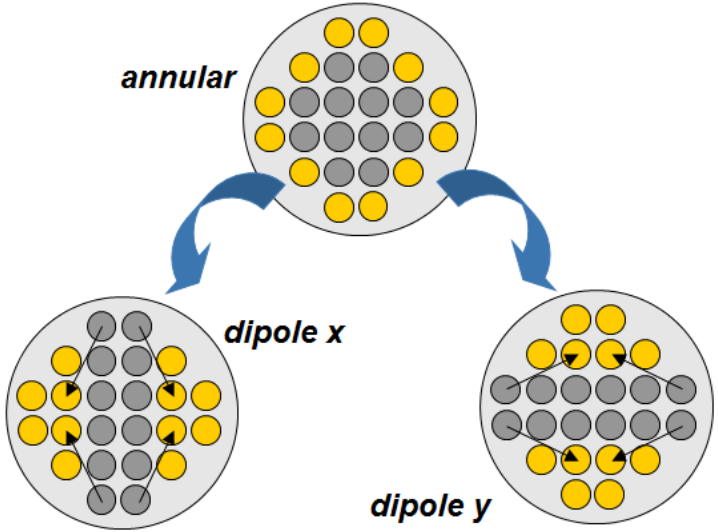
Consistent performance of 0.33 NA lens

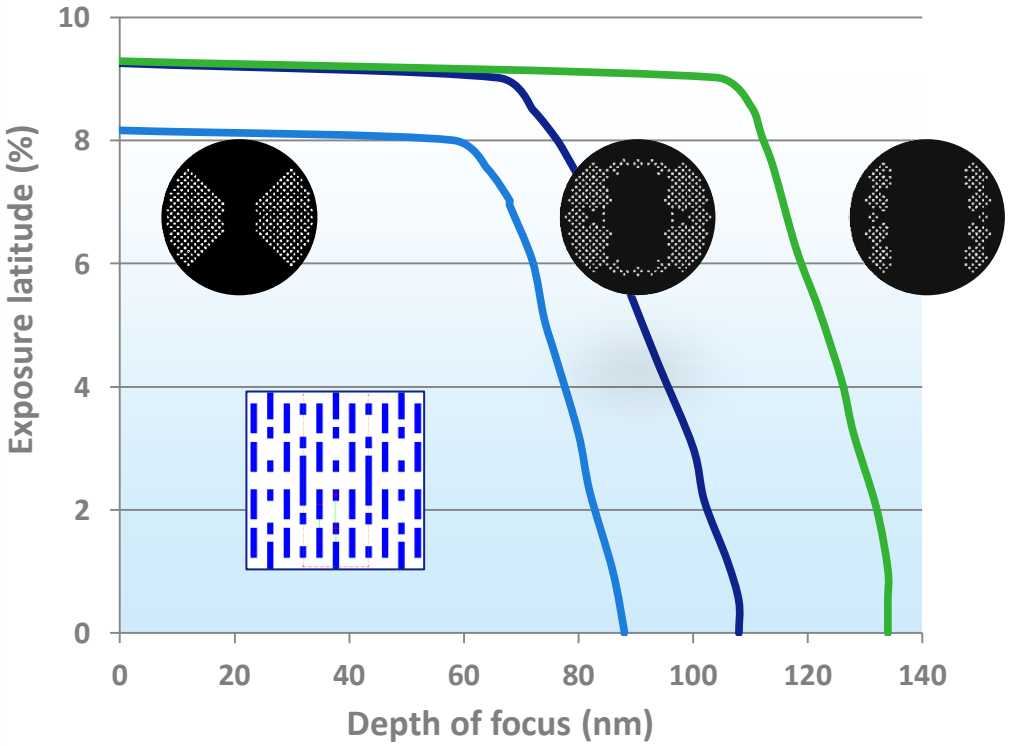
Wavefront error improved by a factor of 2 wrt 0.25NA lens





The NXE:3300B offers new concept off-axis illumination to enhance process window

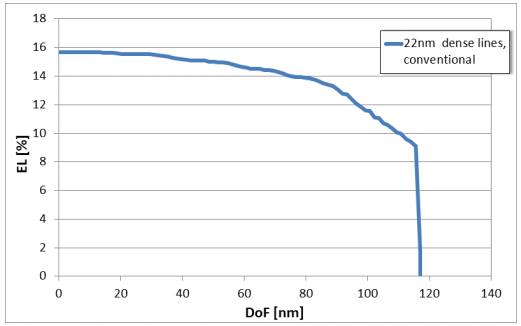




Simulations by Tachyon SMO NXE

Presentation: Martin Lowisch (Zeiss SMT AG)

22nm dense and iso line-space NXE:3300B with an exposure latitude of >16%



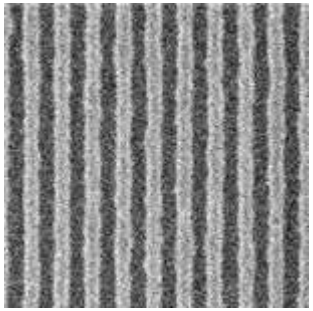
Conventional illumination

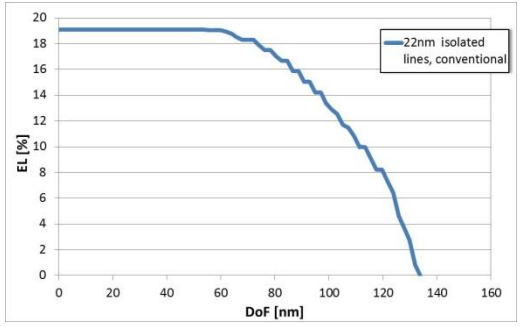
BE = 19.5 mJ/cm^2

LWR = 3.8nm

EL = 16%

DoF = 130nm





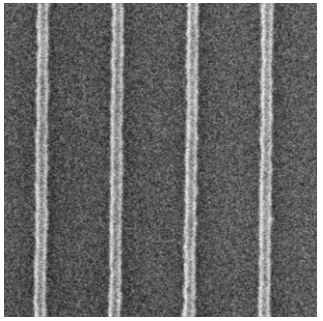
Conventional illumination

BE = 19.5 mJ/cm2

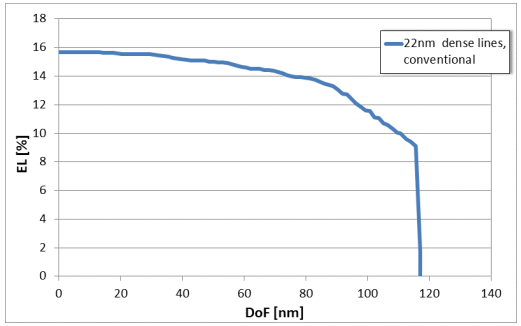
LWR = 2.9nm

EL = 19%

DoF = 130nm



Off-axis illumination enables enhanced contrast and supports ~20% dose reduction while maintaining LWR of 3.8nm



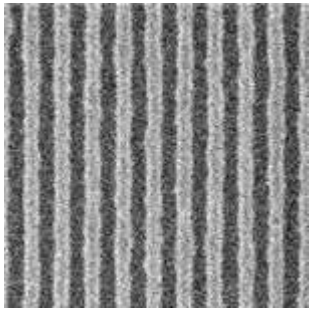
Conventional illumination

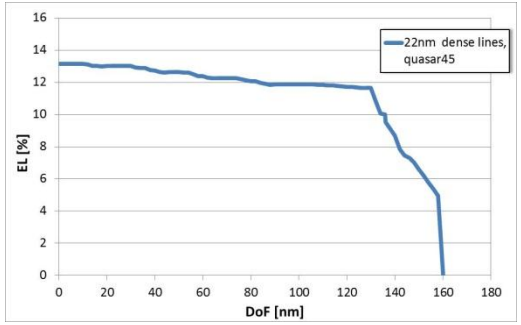
BE = 19.5 mJ/cm^2

LWR =3.8nm

EL = 16%

DoF = 130nm





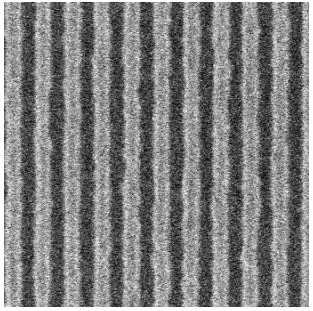
Quasar45 illumination

BE = **15.9** mJ/cm^2

LWR = 3.8nm

EL = 13%

DoF = 160nm

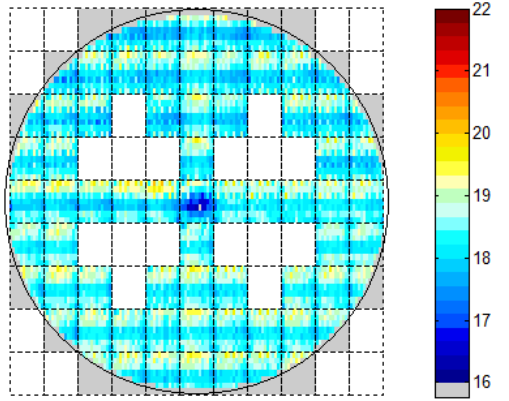


Higher contrast = lower LWR. Lower dose = higher LWR. Higher contrast + Lower dose = same LWR.

Full wafer CDU performance for 22nm dense and iso lines at required performance level

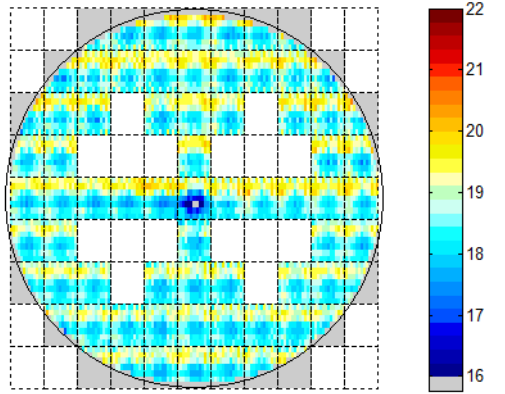
Dense lines H

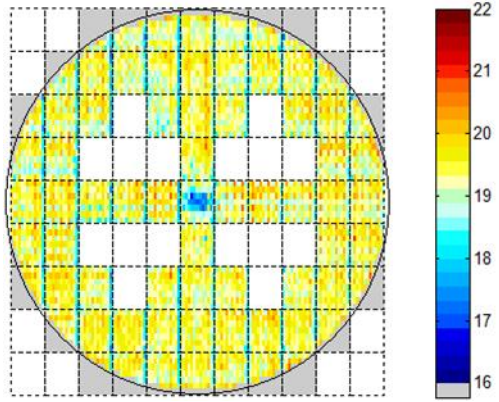
FWCDU = 1.5nm



Dense lines V

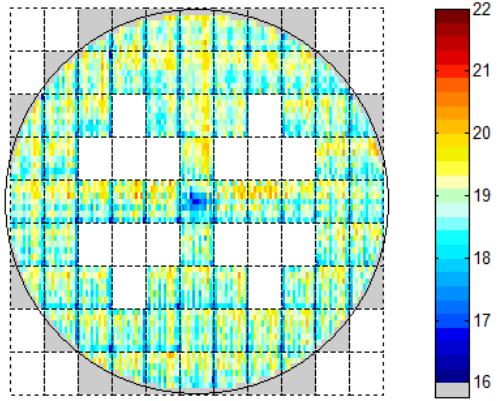
FWCDU = 1.4nm





Isolated lines H

FWCDU = 1.6nm

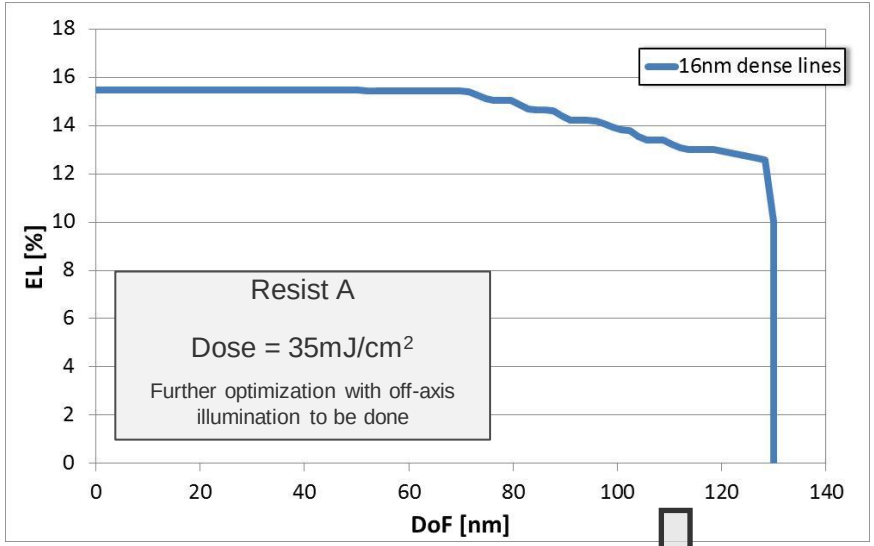


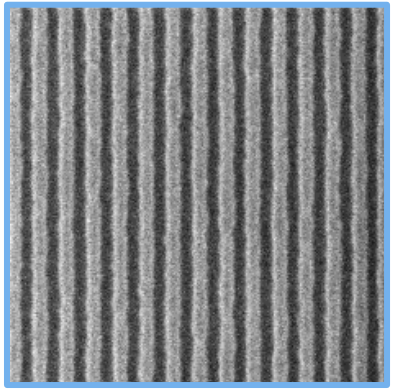
Isolated lines V

FWCDU = 1.7nm

Measured with Yieldstar, targeted with SEM

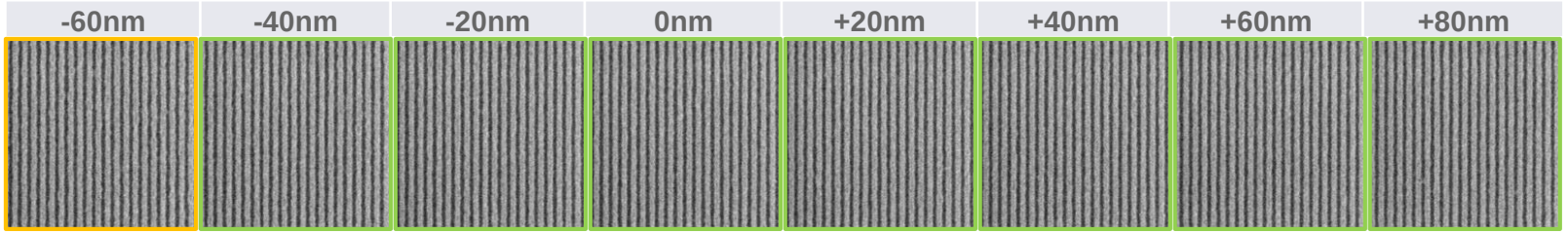
16nm dense lines with >15% exposure latitude and >120nm DoF on NXE:3300B (dipole-45 setting)





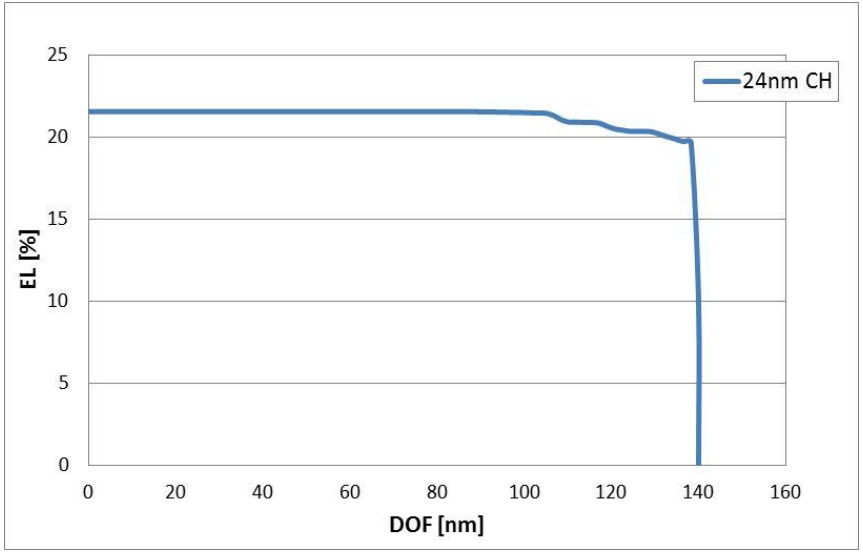
16nm L/S Dipole 45X
29.0mJ/cm2
Resist B

imec

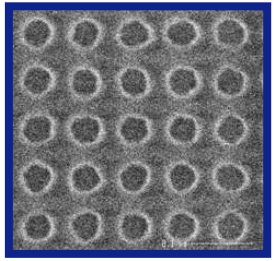


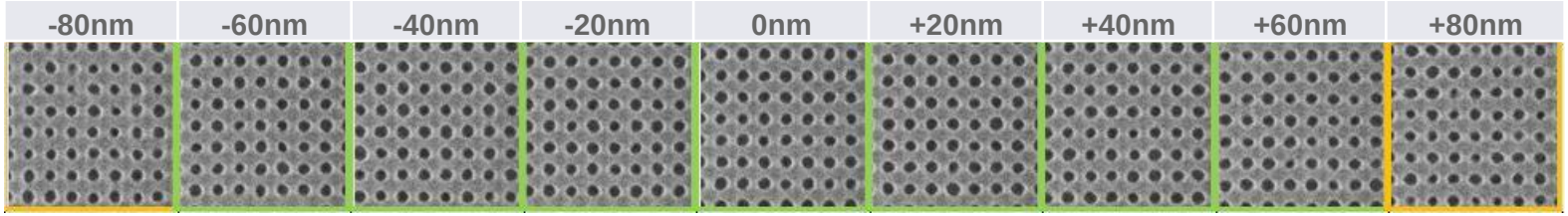
24nm regular Contact Holes (DRAM 1x node) with Exposure Latitude >20%, and DOF >120nm

Single exposure
Conventional setting



LCDU = Hole-to-hole variation over 25 CHs [nm 3σ]



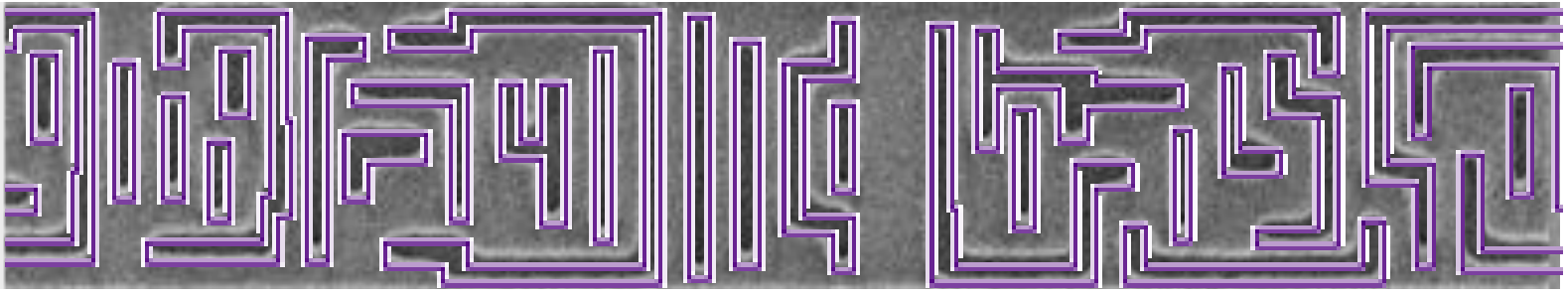


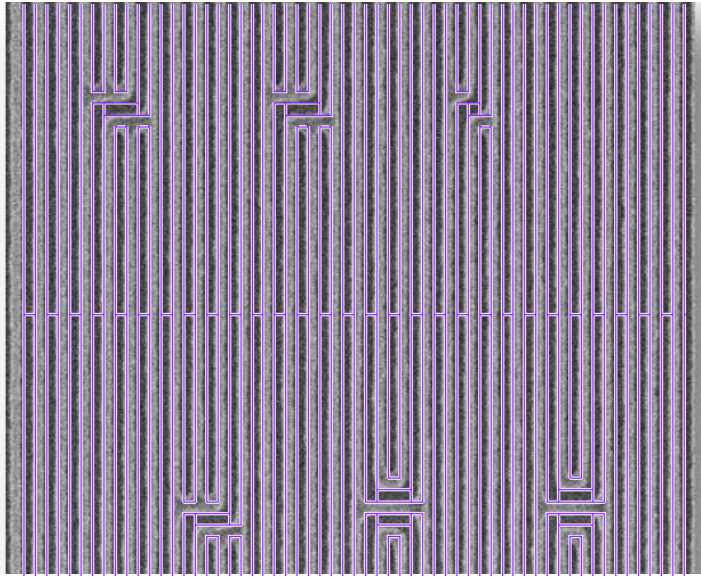
Resist A
26mJ/cm²

LCDU [nm 3σ]	-80nm	-60nm	-40nm	-20nm	0nm	+20nm	+40nm	+60nm	+80nm
	4.0	3.6	3.2	2.9	2.8	2.9	3.2	3.2	3.8

NXE:3300B enables single exposure logic metal1

minimum half-pitch 23 nm, conventional setting

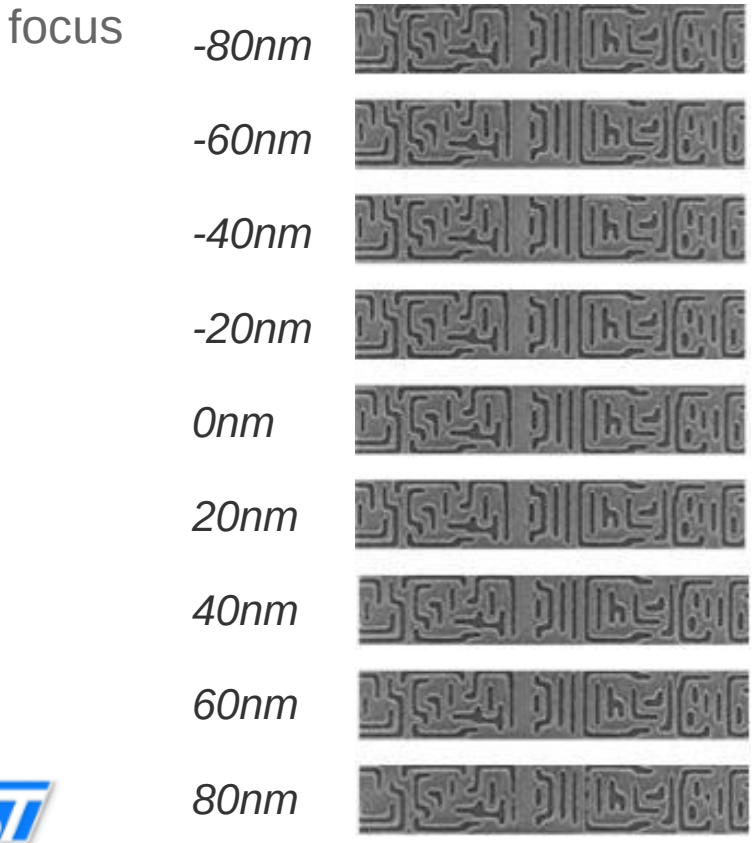




Metal 1 random logic, half pitch=23nm

illustrates sweet spot for EUV @0.33 NA

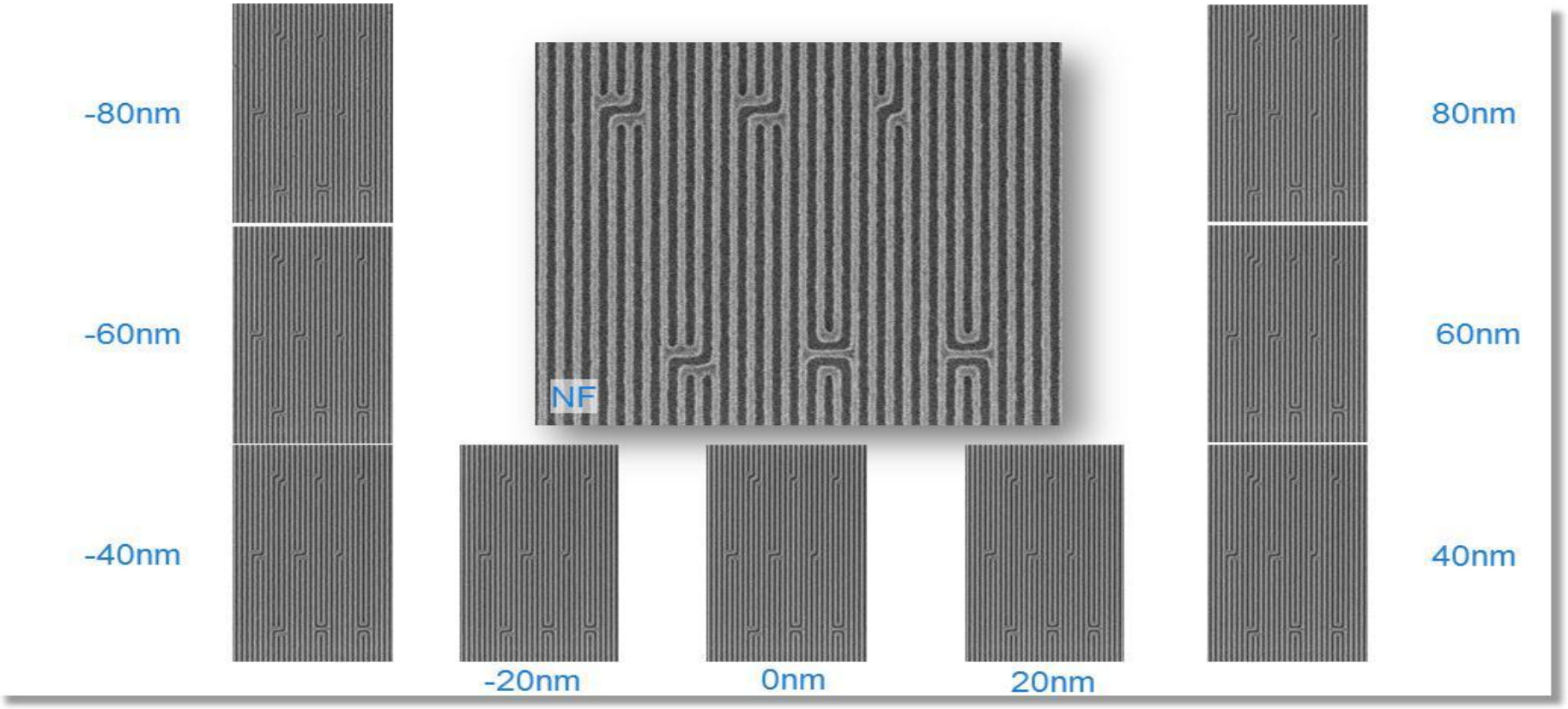
focus



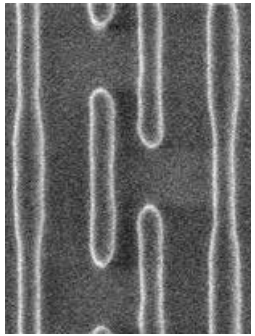
EUV	ArFi
▪ Single Exposure	▪ Double Patterning (LELE)
▪ Usable DoF Current >120nm	▪ Usable DoF typical ≈ 40..60nm

NXE:3300B - Good imaging performance logic metal1

minimum half-pitch 23 nm, single exposure printing



SRAM 2D features: 42nm Tip2Tip performance

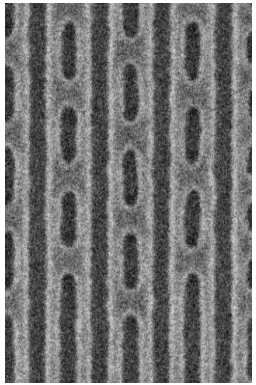


imec

ArFi 28nm node SRAM 90 pitch

Tip2Tip distance (CD) = 80nm

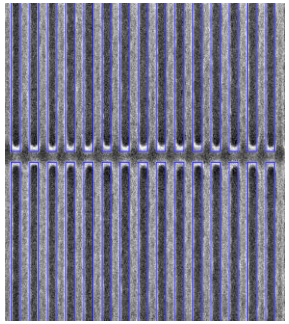
Interfield CDU = 8nm



EUV 10nm node SRAM 44nm pitch

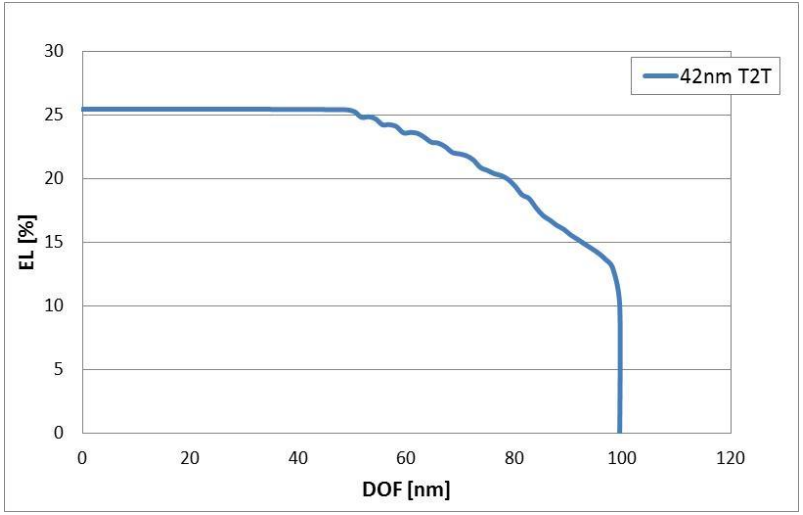
Tip2Tip distance (CD) = 42nm

Intrafield CDU = 1.3nm

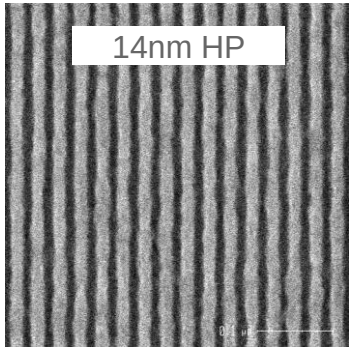


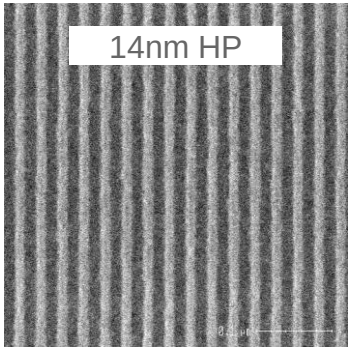
Process Window of line-ends with

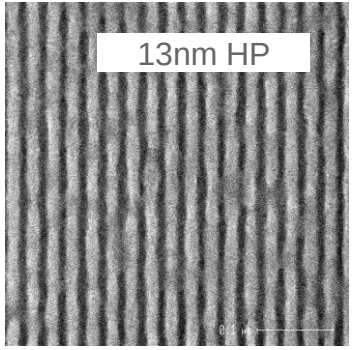
Tip2Tip CD=42nm

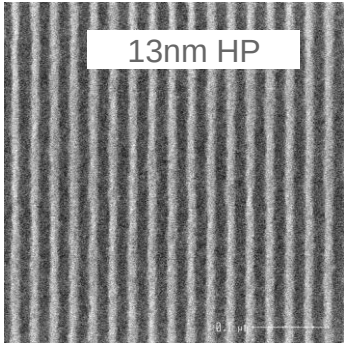


Resolution shown on NXE:3300B for dense line spaces, regular and staggered contact holes; all single exposures







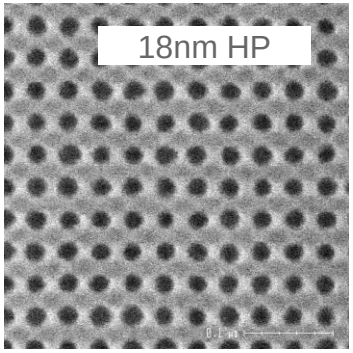


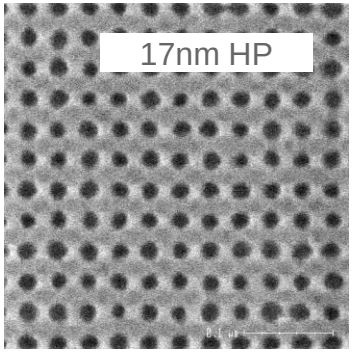
Dipole30,

Chemically Amplified Resist (CAR)

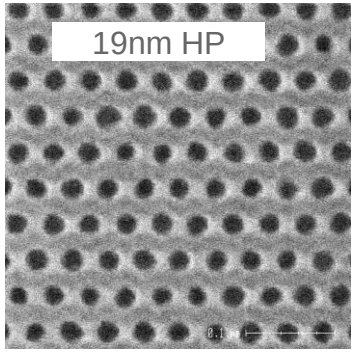
Dipole45,

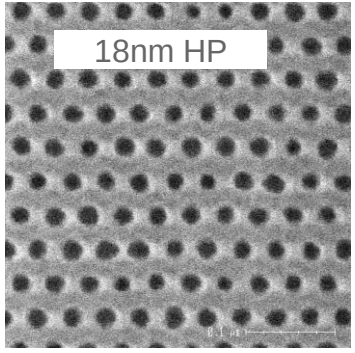
Inpria Resist





Quasar 30 (CAR)





Large Annular (CAR)

NXE:3300B shows single-digit (9 nm HP) patterning capability!

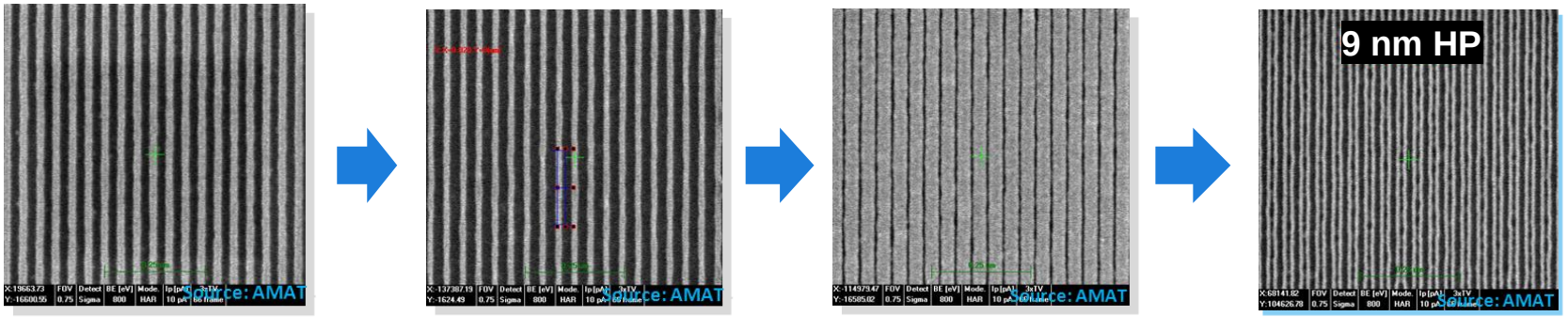
using spacer-assisted double patterning (SADP)

NXE litho
(single expose, 18nm HP)

Core etch

Spacer dep.

Spacer etch



Demonstrated 9 nm half-pitch L/S pattern with EUV single SADP flow.

Litho Conditions:

- ASML NXE:3300B system
- EUVL single expose 18nm HP
- 0.33NA, Dipole-90x illumination
- Resist: 50nm EUV J1099 on 20nm BS AL412 UL on stack wafer with Hard mask

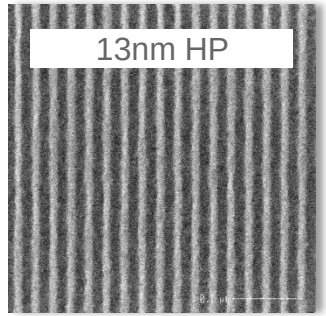
Source: ASML, IMEC, AMAT (Feb.'13)

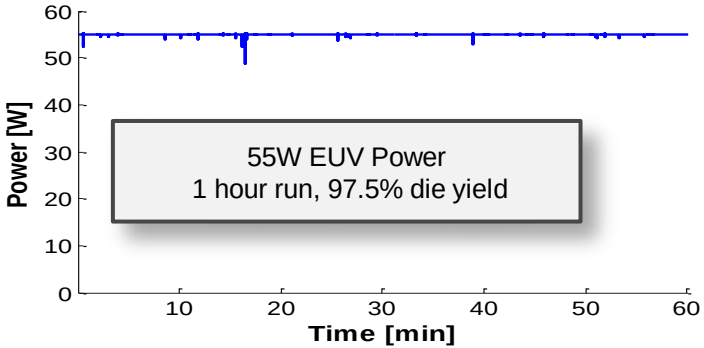
Contents

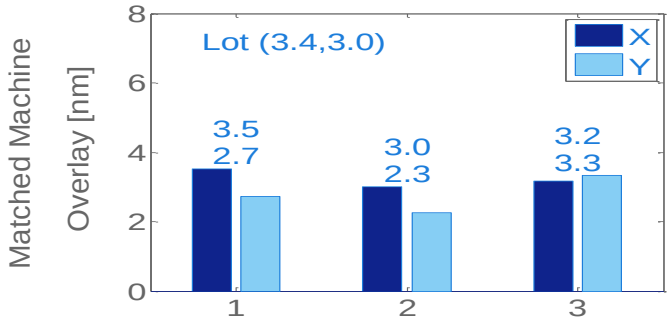
Summary

- **NXE:3100** in use for process and device development at customers

- **NXE:3300B** tested and qualified, 11 systems in various phases of integration
  - Overlay performance of DCO<2nm and MMO<4nm demonstrated
  - Good imaging performance for 1D (22nm to 16nm), 2D (Contact Holes and Metal 1) shown
  - Dose reduction to <16mJ/cm2 for 22nm achieved by utilizing contrast enhancement with off-axis illumination
  - Resolution of 13nm LS and 18nm Contact Holes demonstrated. Further process optimization to be done
  - 40W source power demonstrated with good dose control *and* under good collector protection conditions in six 1-hour runs, and 55W source power demonstrated in 1 hour run with good dose control and same collector protection conditions







Acknowledgements

The work presented today, is the result of hard work and dedication of teams at ASML and many technology partners worldwide including our customers

Special thanks to our partners and customers for allowing us to use some of their data in this presentation

ASML and partners are grateful to the Dutch, German Flemish and French governments for their financial contributions and to the CATRENE organization